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Public Lighting in France and in England at the Present Time

By L. GAYMARD *(Member)**

(1) Introduction

No one is ignorant of the considerable industrial and economic difficulties, which we have faced in France ever since 1939 not only in technical research and new developments, but even in the renewing of equipment and the maintenance of the existing installations.

Public lighting has, more than any other branch, suffered from these bad conditions. The towns of our country must therefore be satisfied for a while with barely sufficient lighting, plainly inferior to what we consider as desirable from the point of view of security and comfort. For example, in Paris, lamps are under-run to lengthen their average life to 2,000 hours and thus to reduce the cost of inspection, the number of personnel, the amount of petrol and the number of lamps used; all this, of course, to the detriment of the flux distributed. We do not acquiesce in the insufficient lighting to which we are doomed by the difficulties of the times, and in what follows, I have intentionally taken no account of our temporary shortages.

(2) French Street Lighting Practice

What is obviously required, before anything else, from a public lighting installation, is to assure the users (drivers and pedestrians) of sufficient and sufficiently comfortable vision of both fixed and moving objects. This means not only high mounting of the lanterns above the road surface but, above all, sufficient contrasts of luminosity between the obstacles and the background against which they are outlined.

We distinguish two main types of public lighting:

1 — Urban lighting

2 — Highway lighting.

They differ in the ratio of the density of the pedestrian traffic to the vehicular traffic, which ratio has a finite value in the first case, whilst it tends to zero in the second.

(2.1) Urban Lighting

The lighting must satisfy:

(a) the pedestrian, looking at objects at short range (30 metres average)

(b) the driver of a vehicle travelling at reduced speed and having to discern an obstacle at a minimum distance of 50 metres.

In both cases we are concerned with vision at distances of the same order as the spacing. In those circumstances, and for want of a better criterion, we find that the criterion of horizontal illumination gives good results, especially in the case which occurs frequently in towns, of a road surface composed of small stone setts giving a fairly good diffusion of light.

(2.2) Highway Lighting

Highway lighting systems are designed exclusively for the drivers of vehicles, particularly for motorists, who must perceive obstacles from a great

* Chief Engineer, Street Lighting Dept., Electricité de France. President of the Association Française Des Eclairagistes. Address presented at a meeting of the Society held in London on May 10, 1949.

distance (100 metres minimum). We have not adopted any criterion in this case: we recognise the importance of the brightness (luminosity) of the road, the obstacle having to appear as dark against a light background (from usual viewing distances of about 100 metres). The use of brightness meters is not yet usual in our country.

(2.3) Assessment of Public Lighting Installations

Street lighting installations are usually assessed by inspection in situ, taking into account the visibility of obstacles and the absence of glare. Attention is drawn to the testing rules which have been established by the General Syndicate of Electrical Construction. Those rules are being examined by l'Union Technique de l'Electricité, with a view to their conversion into standards by which a figure of merit can be designed.

The criterion of good horizontal illumination is important in towns, on account of the number of pedestrians.

(2.4) Lanterns and Light Distributions

We, in France, are particularly sensitive to glare, and public lighting engineers avoid lanterns giving excessive intensities in the direction of the observer, which, at the low background brightness involved, cause dazzle by which the visual capacities of the observer are considerably reduced and his reactions impaired. Modern lanterns therefore provide a maximum intensity at angles of 70 to 78 deg, to the vertical, and the maximum never occurs, as it does in certain other countries, at angles of 80 to 85 deg. We also prefer road surfaces with good diffusion and light in colour (for instance, concrete and stone setts).

We utilise, as optical systems, mirrors or reflectors*, refractors and mixed systems. They are in some cases enclosed in globes or diffusing bowls. For squares and junctions, and generally speaking in spaces presenting areas of the same dimensions around the lighting apparatus, we adopt, in principle, symmetrical light distribution lanterns which light a circular area. (These lanterns may also be used on refuges situated in the centre of very wide avenues.) In streets of average width the area lighted by each lantern is of rectangular shape, the length being rather greater than the width; in this case asymmetrical light distribution lanterns are used. In the lanterns used hitherto, the light distribution has the shape of a pyramid or cone, so that the surface of contact of the beam with the ground has approximately a rectangular lengthened or elliptic shape†; the angle to the vertical of the direction of maximum intensity of the beam of these asymmetrical light distribution lanterns is, whether adjustable or fixed, about 70 deg. to 78 deg., according to type. Axial asymmetrical light distribution lanterns are especially designed. The angles of maximum intensity are of the same order as those mentioned above. Correct results may be obtained with these lanterns mounted over the kerbs by inclining them more or less according to the width of the road.

(3) Spacing and Location

(3.1) Spacing

If the road is not to present to the observer a succession of alternately bright and dark areas, it is necessary for each lantern to provide sufficient luminous flux as far as (and even a little beyond) the next lantern. Since,

* In silvered glass or anodised aluminium.

† The desired distributions are obtained: either with lanterns tilted by an amount varying with the width of the road in such a way that the light beams cover the whole surface of the latter; or with lanterns the optical system of which is designed so as to give suitable distribution without tilting the lantern.

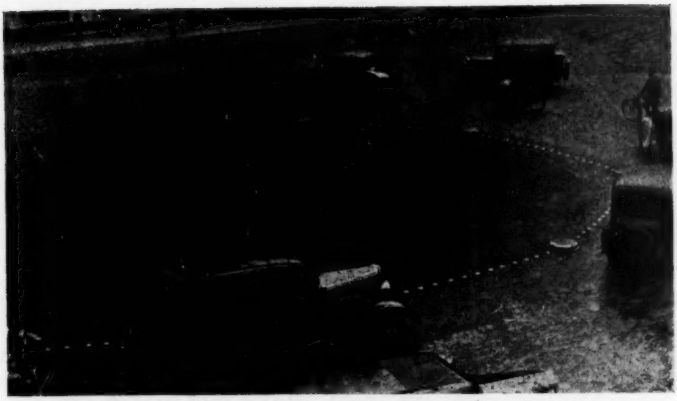

Fig. 1. Traffic roundabout, Place St. Augustine, Paris.

however, it is absolutely necessary to obtain this result without causing glare, one cannot have recourse to a too high peak angle, and consequently it is necessary to limit the spacing-height ratio. As a rule, a ratio of 4:5 should not be exceeded. This leads, for example, to a recommended spacing of 35 to 36 metres for a height of 8 metres. If, for local reasons or convenience, of maintenance, lower mounting heights must be adopted, it will be necessary to reduce the spacing: e.g., 33/34 metres for 7 m. 50, 30/32 metres for 7 m., etc.

The choice of the values recommended above has not only the advantage of making for a uniformity of brightness satisfactory in wet as well as in dry weather, but it also ensures sufficient illumination of moving obstacles throughout their track, which approximates to daylight conditions of vision and aids the vision of these obstacles and visibility in the street. In a good number of our present installations the ratio between the spacing of the lamps and their height is too great. The result is, on many smooth roads in dry weather and on most wet roads, dark dangerous areas which usually appear immediately behind the lamp posts.*

(3.2) Location of Lanterns

In choosing the type of location of the lamps, we consider first the width of the street, to determine whether lanterns placed on the kerb will be able to illuminate the whole width. This depends on the shape of the light distribution of the lanterns and the height at which they can be mounted. Our present standard asymmetrical light distribution lanterns can light roads of a width about equal to the mounting height.

When the mounting height of the lanterns has been chosen according to the local conditions and the recommendations of the previous paragraph, the road will be classified in either of the two following categories:

A—roads the width of which does not exceed (or is a little over) the height adopted for the lamps,

B—roads the width of which exceeds markedly the height of the lamps.

* The proportion 4.5 given above presumes the use of sources of high brightness, such as incandescent or mercury H.P. lamps, in asymmetrical light distribution lanterns of good quality with two symmetrically arranged beams.

If low brightness discharge sources are used (e.g., sodium), which by their dimensions lead to distributions having lower maximum intensities than those of the preceding lanterns, it will be wise not to exceed a spacing height ratio of 4.

The following rules are recommended:—

SPACING AND MOUNTING HEIGHT.

Maximum spacing-height ratio.—4.5 for tungsten filament and mercury high pressure, 4 for sodium vapour lamps.

Recommended values.—For tungsten filament and H.P.M.V., height 8 m., spacing 35 m., or height 7 m. 50, spacing 33 m. For sodium vapour lamps: height 8 m., spacing 32 m.

ARRANGEMENT.

Category A. (in which the width of road does not exceed or is a little over the height of the lamps) staggered (or unilateral if financial considerations or the type of overhead electric supply make it compulsory.)

Category B. (in which the width of road exceeds significantly the height of the lamps) the use of lanterns on both sides is compulsory, with opposite arrangement. For very wide roads, it is important that the height of the lamps should not be less than half the width of the road. Special lanterns with a wider distribution may be used with advantage, especially when wall brackets are used.

(3.3) "Skim Effect" Lighting

It is often suggested that public lighting should be carried out by "skim effect" lighting, by lamps located at a very low height and giving out a "sheet" of light. This device has the advantage of avoiding high columns, sometimes inaesthetic and often costly. Nevertheless, the use of such a system is not to be recommended, except in quite exceptional cases.

This system has the following disadvantages:—

(a) Lighting of vehicles and pedestrians is limited to a reduced height which makes difficult the identification of obstacles, these usually being lighted up to mid-height only.

(b) occultation of lamps by passing vehicles or pedestrians.

(c) production of very long shadows projected in front and behind obstacles, the size of which changes more quickly as the speed of the vehicle is greater.

(d) direct glare is often difficult to avoid because the lamps are too low and always within the field of view.

(e) Severe glare is inevitable when the road surface is wet, since the beams, being directed very close to the horizontal, undergo reflection which is nearly specular and the road surface brightness becomes of the same order as that of the luminous source.

(f) Lamps located low are necessarily accessible to the public and it is very difficult to protect them against theft or malevolence. This can only be effected by protection by toughened glass, or strong grilles, which obstruct a significant fraction of the light flux and give rise to rapid soiling by dust or mud thrown up by vehicles.

As the result of all these disadvantages, in spite of the interest that such a system seems to offer, in particular in the case of lighting of bridges, it should not be used, except when for some reason the fixing of lamps to brackets or poles is absolutely impossible and when only short sections are concerned.

3.4) Obstruction of Trees

Lamps should be set as near as possible to the kerbs and, if necessary, brackets used which project beyond the pavements and avoid screening by trees. It will often be advisable to have brackets projecting by 2 m. 50 at least.

If it is impossible for the planting Service to prune the trees sufficiently,

lower mounting heights could be used provided that the spacing/height ratio of 4.5 is respected.

(4) Classification of Roads and Power of Lamps

The power of lamps is generally a function of the width of the roads to be lighted, and it is also related to the height of the lantern. In towns, the height of the lamps varies normally from 5 metres (parks, gardens, lanes in residential areas) to 8 metres for the lighting of ordinary roads and to 12 metres for the lighting of main roads. In exceptional cases, for the lighting of wide spaces or public buildings (e.g., in Paris: Palais de Chaillot, Pont du Carrousel, Place Saint-Augustin, Place de la Bastille, etc. . . .) we have recourse to lanterns set very high up at 22 metres and exceptionally at 28 metres (e.g., Palais de Chaillot). Such installations are rare, in consideration of the difficulties of maintenance at such heights. For roads in towns we recommend the following heights:—

Width of Road	Height of Lamp
10 m.	6 m. 50
12 m.	7 m. 50
16 m.	9 m. 50
20 m.	10 m. 50

Certain values of luminous flux per metre length of roadway have become accepted for roads of various sizes as regards both their dimensions and the volume of traffic. Table 1 gives for different values of volume of traffic and different widths of roads the arrangement of lamps to be adopted and the

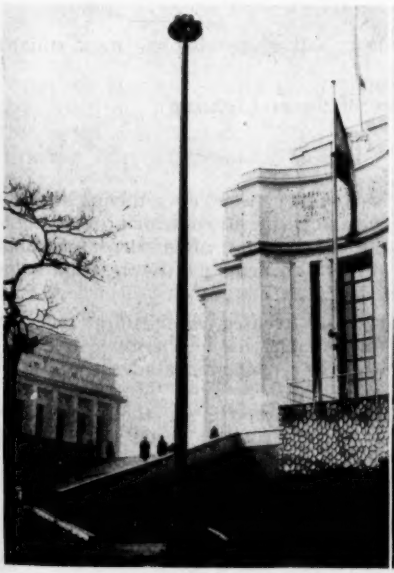

Fig. 2. *(Left)* Exceptionally tall lamp standard at the Palais de Chaillot.
Fig. 3. *(Right)* One of the four columns on the Pont du Carrousel.

Table 1.

Classification of Roads in France for Street Lighting.

Class	Type of road		Average width in meters	Type of lighting	Width of road	Recommended arrangement of lamps	Flux emitted per lantern per metre length(lumens) (mean during life)	Average horizontal illumination (lux)
Unclassified	Special circuses Squares, etc.		—	—	—	—	—	—
1st Class ...	Heavy traffic roads	B	12 m.	High power lighting	$d > h$	Bilateral staggered or opposite	240 to 370	8–12
		A	6 m.	High power lighting	$d \leqslant h$	Bilateral staggered	200 to 240	
2nd Class ...	Average traffic roads	B	12 m.	Medium power lighting	$d > h$	Bilateral staggered	130 to 170	4–8
		A	6 m.	Medium power lighting	$d \leqslant h$	Bilateral staggered or unilateral	100 to 120	
3rd Class ...	Low traffic roads	B	12 m.	Low power lighting	$d > h$	Bilateral staggered	55 to 75	1–4
		A	6 m.	Low power lighting	$d \leqslant h$	Unilateral or central	35 to 55	
Unclassified	Lanes		—	—	—	Unilateral	—	Beacon lighting

NOTES.—d : width of road ; h : height of light source. In every case the height of the light source should be between 7 m. 50 and 9 m. 50, the maximum height being recommended for wide roads. Distance between lamps should be 31–36 m. on each side for roads in category B (width exceeding height) and in the case of central lighting, and double this for roads in category A. These recommendations apply to present-day lanterns. The higher efficiency of fluorescent lamps allows the use of units of higher light output.

luminous flux per metre length of roadway. It gives also the most suitable heights.

(5) Present Tendencies of Street Lighting

(5.1) Tendencies in Lanterns and Light Sources

(a) Lanterns.

The development of new lanterns slackened considerably during the war and occupation. However, several tendencies can be noted which are likely to modify more or less the conception or the construction of lanterns for public lighting as they existed in 1939. The principal items to point out are the following:—

(i) The very widespread use of specially treated aluminium reflectors instead of silvered glass reflectors. Particularly severe tests, carried out either at the sea-side or in laboratories, have demonstrated the excellent behaviour of this type of reflector.

(ii) A great development of asymmetrical lanterns of the ovoid type. Adjustment, as a function of the width of the road, is made by tilting the lantern appropriately.

(iii) Research with the aim of designing lanterns which involve simpler maintenance, and which avoid the reduction of flux by accumulation of dust.

(iv) Designs of lanterns giving a better distribution of flux, so as to obtain a greater uniformity in the brightness of the carriageway.

(v) Attempts are being made to design lanterns utilising either low voltage

or high voltage luminescent lamps. Some designs are already in use, more particularly with low voltage fluorescent tubes.

(b) *Light sources.*

In Paris the proportion of the different types of luminous sources in the various categories of roads is not, generally speaking, the result of predetermined planning but of a " de facto " condition due to the evolution of techniques and to the financial possibilities, either for new or for redesigned installations. Moreover, it is not possible in Paris to discriminate between such categories as highways, residential areas or business districts, thoroughfares or streets, etc.

At the beginning of the nineteenth century, low pressure gas lanterns came into general use. Then high pressure gas lighting (with 1,500 mm. water pressure) which permitted more powerful lamps to be produced superseded the low pressure gas in the wide and important thoroughfares. But electric filament lighting is at present progressively superseding high pressure gas. Finally, fluorescent lanterns have been erected in certain underground tunnels and on several hundred metres of public roads. The present situation in Paris can be summed up as follows:—

Table 2.

Numbers and Types of Public Lamps in Paris.

Type of Light Source	Number of lights	Proportion
Electric Filament Lamps ...	32,300	75.5%
High pressure gas	5,050	13%
Low pressure gas	6,700 out of which 4,500 are in operation	10.4%
High pressure Mercury vapour	130	0.3%
Fluorescent	350	0.8%

The average power of a lamp in 1939 was 217 watts. To-day it is a little lower, as all the lanterns are not yet provided with lamps of the same power as before the war. The situation of the production of electrical energy does not yet permit a return to normal power.

(5.2) Public Lighting by Sodium Vapour Lamps

The spectral characteristics of the orange-yellow monochromatic light given by the sodium vapour lamps have been greatly utilised in France for public lighting and for exterior lighting of large spaces. Even before the last war, numerous applications had been made in the lighting of sections of high traffic roads in the suburbs of several towns, e.g. Paris, Lille, Dijon, Grenoble, Bordeaux. The success of these installations had suggested large-scale plans like the lighting of trunk roads of the first importance, such as the Paris-Nice road. The present situation has not yet permitted the resumption of these plans, but new installations are now being carried out on small sections of roads outside the towns.

On the other hand, the considerable destruction of the war having affected the ports and railways, we have had recourse for their lighting to sodium lamps; for instance, the harbours of Bordeaux, Le Havre, Dunkerque, Boulogne, the parks, dock-yards and sidings of the Société Nationale des Chemins de Fer Française, have been provided with large installations. The number of lamps now in use amounts to a few thousands, and there is provision for large future installations. These installations are generally carried out with lamps of average power of the type SO 650-85 watts (105 watts with the ballast)—giving

6,500 lumens. They are used in lanterns consisting of a metal frame which houses two cylindroparabolic mirrors made of refined aluminium, protected and polished by an electrolytic process. By adjusting the tilt of these mirrors and of two lateral shields meant to suppress glare, a good light distribution is obtained on the ground. In the marshalling yards, the height above the ground is frequently 10 to 12 metres.

All the installations are very satisfactory to the users, who observe considerable accentuation of contrasts, and a real improvement in visibility, increasing the ease of movement in traffic, and the conditions of work in misty as well as in clear weather.

The monochromatic light of sodium vapour prevents discrimination of colours, and gives to faces a livid complexion, e.g. a ruddy complexion shows purple lineaments. In France, therefore, these lamps are not used in the central districts of the towns. They are, however, used with advantage in the outlying districts, mainly in the thoroughfares leading out of towns, and in highways.

(5.3) Fluorescent Public Lighting

There exist already in Paris a certain number of low voltage fluorescent public lighting installations*. In all these it has been recognised that the best results could be obtained with lanterns having several tubes set nearly horizontally and perpendicularly to the axis of the road way. The result obtained is excellent from the triple point of view of:—

Comfort for both pedestrians and drivers;
Visibility of obstructions;
Lack of glare.

However, the lanterns now on the French market will have to be improved, especially in following points:—

Obtaining a good luminous output in all weathers;
Resistance of the lanterns to weather conditions and corrosion;
Easy replacement of tubes and various fittings.

In Avenue du Président Wilson the existing lamp columns were used, and the spherical refractors, which were provided with 300 watts incandescent lamps, were replaced by lanterns each equipped with five 1 m. 20 tubes (each consuming 40 watts and giving about 2,000 lumens), the flux of which is distributed by cylindroparabolic mirrors made of electrolytic aluminium, and which are protected by "plexiglas" windows. The comparison with the parallel carriageway, where incandescent lighting has been retained, is plainly to the advantage of the tubes. The impression given by the whole lighting installation, the visibility of obstacles, and the lighting of the pavements, is very good. This trial has not yet been subjected to a severe cold spell.

There seems to be a bright future in public lighting for high voltage fluorescent tubes. These tubes, with an efficiency and a cost comparable to those of low voltage tubes, have the advantage of striking properly, even in cold weather, and to have a very long average life (up to 10,000 hours)†. Tests have recently been started in France on the use of high voltage fluorescent tubes for public lighting. They are still at a too early stage to be recorded in this discourse.

A new circuit is likely to be used in the near future which will have advantages in fluorescent public lighting (particularly as far as maintenance

* Avenue du President Wilson, Place de l'Alma, and very likely within a short time Rue du Faubourg Saint Honoré and Place de la Concorde.

† The operation of these lights requires a current of about 600 volts per metre length of tube. The current is very low. A safety switch device automatically cuts off the supply when the high voltage part is to be reached.

and renewal are concerned) and which will be soon put on the market by a French maker. In this circuit, the electrodes are connected to a transformer which provides both electrode heating and tube current. There is no starter: longer life of the electrodes and tube is expected as is the disappearance of blackening at the ends, and instant start at even low temperatures.

(5.4) Superseding of Gas Lighting

Gas and electricity have shared for a long time the duties of public lighting in France, and until recently, gas has had its convinced supporters. But to-day almost all towns have, in principle, given up gas lighting; and if this kind of lighting still exists in some places, it is due to a lack of funds for its replacement by electricity. Public taste, the high cost of gas lighting and of its maintenance, the impossibility of extinguishing it quickly and certainly in case of air raid alarm, and on the other hand the convenience, the cleanliness, the ease of handling and the economy of electric lighting, are the main causes of this development.

(5.5) Directed Flux Lamps

Great difficulties are met with in the accurate adjustment of the position of the lamp at the focus of the optical system. Moreover, even if this adjustment has been correctly performed with a given lamp, it has to be done all over again every time the lamp is replaced on account of tolerances in light centre length of the lamps.

An interesting and economical solution consists of a reflector lamp with 3-pin cap, having an ellipsoidal bulb internally silvered over part of its surface, which thus constitutes the mirror of the lantern. The lamp is protected by an anodised aluminium housing. This lantern is already in fairly wide use, particularly in small and middle-sized towns.

(5.6) Optical Jig

In this type of lantern the lamp and an anodised aluminium reflector are held as a rigid and fixed unit in an optical jig, which can be interchanged as a whole. The lamp and mirror are adjusted and locked at the factory and if a lamp fails the complete jig is replaced.

(5.7) Anodised Aluminium Reflectors

A lantern recently introduced into France* is attractively simple. It consists of a reflector of extra pure aluminium, very resistant to corrosion, and a bracket allowing the lamp position to be adjusted so as to obtain a light distribution which may be either concentrating or spreading, and either symmetrical or asymmetrical†. No globe nor protection of any kind is required.

(5.8) Mounting of Lanterns

When the pavements are narrow, wall brackets may be used; but with wide pavements brackets locate lights too far back, and it is preferable to use columns.

(a) *Columns.*

Lamp columns should preferably be provided with projecting brackets, having average overhang (0 m. 70 to 1 m.) when the road is not planted with

* It is widely used in the large towns of Switzerland.

† The asymmetrical type merely includes a tilted stirrup on which the lamp is shifted by 8 degrees with respect to the axis.

trees, and large overhang (1 m. to 2 m. 50 and over) when the road is planted, so as to avoid the shadow of the foliage.*

On account of their low resistance to shock, cast iron columns are now completely abandoned for new installations, in favour of steel or concrete columns.

(b) *Brackets.*

The use of brackets is recommended for economical reasons in the cases where sufficiently high buildings allow it, and when the small width of pavements compels it. They are utilised when the width does not exceed 22 metres between façades and when the obstruction of pavements does not permit the setting up of lamp columns, and when there are no trees. They are made of steel, cast iron, concrete or steel tubes. They are generally set up by means of bolts cemented into the façades, and are fed through steel armoured conduit conductors or lead covered, iron armoured, taped cables or armoured cables. The overhang of brackets can vary from 0 m. 50 to 4 m. 50. Guys are necessary over 2 m., and when they are fixed to buildings, lateral wind braces are recommended for overhangs of 3 m. 50 and over. A decree of October 15, 1935, gives (with certain safeguards) to the town councils the right to erect brackets on buildings.

(5.9) Standardisation of Equipment

Since excessive multiplicity of types makes replacement difficult and involves costly maintenance and often dissimilar lighting, efforts have been

* This recommendation does not apply, of course, to the lighting of squares or thoroughfares, nor to the lighting of parks and gardens.

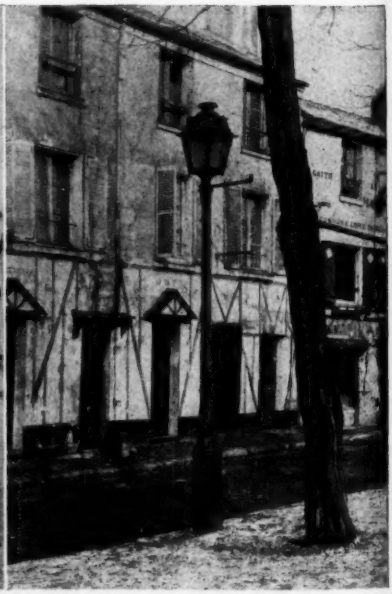

Fig. 4. *(Left)* Wrought iron lantern in the Place des Voges. Fig. 5. *(Right)* Gas lantern in the Place du Tertre, Montmartre.

made, during the last few years, particularly at the Ministère de la Reconstruction et de l'Urbanisme, to reduce the number of types of lamp posts, brackets and lanterns, and to impose certain rules for the supply and control of public lighting. The maintenance budget (the most important part of which is constituted by cost of labour) is greatly reduced by the standardisation, as far as possible of all spare parts and, in particular, of screws. For screws and bolts, inoxidisable metals (bronze, brass, stainless steel) or ferrous metals, protected by hot galvanising, electrolytic galvanising, or blow-pipe zinc spraying are used.

(6) Remote Control

When public lighting is supplied from its own network, the lighting and extinction of lights is obtained by a simple switching at the sub-stations of this network or by remote control to those stations. When the lights are supplied individually, or in small groups from the public supply mains, a control relay is located in each installation (generally housed inside the base of the column or in a box on the façade of the building). The relays are actuated from a distant point.* The three remote control equipments in greatest use in France are the Actadis and Brillié equipments which are used in Paris and the Durepaire-Perlat equipment, which is becoming more and more widely used in our country towns. There is also the system involving the provision of pilot wires near the supply cables, which carry a small current, by means of which public lighting contractors or relays are actuated.

The town of Paris has recently installed in the central part, lying between Boulevard Saint-Germain and the River Seine, remote control and supervisory equipment operated from a central control point for the operation of lights. This equipment makes costly inspections unnecessary; at any time it is possible to check in a few seconds the insulation of mains and the lighting or the extinction of all the lanterns. Moreover, an alarm system gives warning, without any interference to normal operation, of any incidents occurring by night or day, such as partial extinction during the night, or partial lighting in daytime. The installation provides also emergency remote control, in case of a fault in audio-frequency relays. A telephonic device provides a connection between the control point and each public lighting station.

(7) Inspection, Replacement and Maintenance

The maintenance of public lighting equipment involves, as a rule, only very simple operations, but their total in man-hours, is considerable owing to the height at which work must be carried out, and to the great number of lanterns to be inspected and reconditioned. Thus maintenance sets to town councils a problem which is more one of organisation than a technical one.

Periodical tours of inspection (a daily routine being advisable) disclose faulty lights. They are followed by tours of maintenance and repair, during which the faulty installations are overhauled from the triple point of view of electrical and mechanical condition and cleanliness.† During inspection, when tower-wagons or trucks provided with portable ladders are available, it is advantageous to replace failed lamps on the spot. One of the longest (and consequently the most onerous) periodical operations is the correct adjustment of the filament of each lamp. Up to the present, it has not been possible to obtain delivery of special lamps for public lighting, including a prefocused lamp

* These remote control devices also control, in the consumers' flats, relays for tariff change-over and contactors controlling at suitable times, radiators, boilers, etc.

† It should be borne in mind that since dust and mud can absorb up to 30 per cent. of the luminous flux of the lamp cleaning is a "paying" operation.

cap whereby the correct orientation of the filament is accurately ensured and the light centre length maintained constant (which ensures a correct setting of the filament in the optical system, and therefore a correct light distribution). The production of such lamps will secure a better distribution, more nearly uniform and more economically maintained public lighting. Another approach to this problem is the use of the "Optical Jig," described above.

(8) The Aesthetic and Decorative Side

We always have had, in our towns, and chiefly in Paris, the task of adapting the lighting and the design of columns to architectural requirements, and thus to harmonise the shape of lanterns, the distribution of luminous flux and the landscape. Eloquent examples of this aesthetic care are to be found, especially in Paris, the most recent of which is given by the Pont du Carrousel. So as not to interfere with the very sober line of this beautfiul one-span bridge, it has been decided to light it by means of four monumental lanterns, sited at the four corners. The height of 21 metres necessary to ensure good visibility at the centre of the bridge would have seemed excessive; we have therefore had recourse to telescopic columns, 14 metres high in daytime, which are not extended to their full height until lighting-up time. Other examples are the graceful wrought-iron lanterns on la Place des Vosges, and the small gas lanterns of la Commune Libre de Montmartre, the picturesque outline of which has been retained.

We utilise in Paris several coats of galvanic paints; a paint which tends to give the lamp posts the appearance of bronze with a certain artistic weathering. Moreover, the coat of paint was, before the war, completed by polishing of the lamp post. At present, for economical reasons, these processes are no longer strictly applied.

As an example of the influence of the "Services d'Architectures et des Beaux-Arts" upon the choice of the lanterns, we can say that it has not been possible yet to install, on the Place de la Concorde, and the Champs Elysées, rational lighting by means of very high lamp posts; telescopic standards proposed for la Concorde have not been accepted. As for the Champs Elysées, it has been feared that a line of high-mounted lights would tend to decrease, to the eye, the majestic width of this avenue.

In ordinary streets the exterior aspect of lanterns has been laid down for the engineers in charge of the planning of lighting equipments. This is the case for the Avenue de la Grande Armée, where it has been necessary to design a spherical refractor distributing the flux as well as possible. The four monumental lanterns of the Pont du Carrousel have also been designed from the point of view of their exterior appearance in order to contribute to general architecture of the site, much more than from the point of view of lighting possibilities.

It is with the same end in view that, in an attempt to rid the pavements of unnecessary poles, we so often replace lamp columns by brackets set on the façades of buildings. It is, moreover, mostly aesthetic considerations which in Paris, have led us to avoid entirely central suspension (to-day, nearly everywhere condemned, as it invites drivers to drive in the middle of the road) and concrete lamp columns, notwithstanding their cheap maintenance. For aesthetic reasons we also avoid overhead networks in towns, and aluminium paint (however practical it may be!). If we feel reluctant to use, in the smart districts, sodium vapour or mercury lighting it is, above all, in the name of aesthetics.

(9) Lighting of Monuments and Public Buildings

Here, more than anywhere else, we endeavour to harmonise, in each particular case, the lighting to the architectural character of monuments and beautiful squares. This leads either to very high lamp posts (as those around the Palais de Chaillot, Carrousel or Place de la Bastille), or to numerous low-located lights (as, for instance, Place de la Concorde).

International exhibitions provide a magnificent field for experiment in the lighting of wide spaces, and bring to the fore the architectural aspect of electric lighting. Thus, at the exhibition of 1937, we saw not only columns of varied shapes—with direct or indirect lighting—creating among the pavilions and in the gardens astoundingly rich effects, but also powerful vertical, horizontal or skimming sheets of light which enhanced the daring shapes of palaces and the majestic perspective of Chaillot, Champ de Mars and Tour Eiffel. On the River Seine, in the Bassin d'Iéna, there were given, for the first time in the world, displays of fountains, light and sound in which, on every festival night, search-lights, fireworks, music and fountains followed a given theme in harmony. The various festivities which mark the year are no longer conceived in an important town without the illumination of its most beautiful monuments.

The installations for the illumination of monuments and fountains of Paris represent a total connected load of over 3,000 kw. corresponding to the public lighting of a town of 1,000,000 inhabitants.

The art of enhancing happily the relief and the depth of beautiful façades adorned with columns and statues, and of apses with flight-flying buttresses, requires the intimate collaboration of engineers and architects.

(10) Underground Road Tunnels

The lighting of these works give rise to particularly acute problems. The main difficulty comes from the impression of a "blind spot" which the drivers feel when they enter the tunnel in broad daylight. This impression is due to the great difference in illumination levels, when sunlight gives, even in cloudy weather, ground illuminations of several thousand lux, whereas an artificial illumination gives (unless very expensive installations are used) illuminations of only from 100 to 200 lux, resulting in obviously insufficient brightness both of the edge of the pavement and of vehicles.* We have, therefore, endeavoured to augment the illumination, and certain installations include automatic increase of the lighting of the tunnel in clear or sunny weather.† The illumination obtained remains, however, so much less than that of daylight that attempts have been made to mark the kerb with retro-reflectors. But the best solution seems to be lighting entrance and exit openings by sunlight, by glazing the walls and if possible the vault. Such a solution is, unfortunately, not always practicable.

It has been used in Paris for the Clignancourt tunnel and it will be used, too, for the Croix Rousse tunnel in Lyon. Another excellent solution consists, in the case of two one-way tunnels, in the installation of a lighting system by means of projectors tilted towards the road way, facing the traffic.

(11) Comparison Between British and French Tendencies

It is obvious that, on the whole, a close analogy exists between the rules which have been adopted for public lighting in our two countries. It is

* Interesting results can be obtained through the use of large numbers of fluorescent tubes, which have an efficiency of two to three times that of tungsten filament lamps. The 1,800 metres tunnel at La Croix Rousse at Lyon will give an example of such an installation.

† A photo-electric cell provides this control. The present installations can give 150 lux in full sunshine.

equally obvious, moreover, that in England a high standard of technical achievement has been attained in both domains. No French experts on these problems could claim to teach their British colleagues anything new. The parallel I propose to establish, at the request of the President of the Society, between tendencies in the matter of public lighting in both countries, will only reveal differences in detail resulting from our respective customs. They may be summed up briefly as follows:—

(i) *Classification of Streets.*

Instead of adopting a classification into two categories as in the British Ministry of Transport Report we classify roads less rigidly. Taking into account the ratio d/h, we make a distinction between high-traffic, average-traffic, and low-traffic roads, thus allowing greater freedom in the design of the installations.

(ii) *Importance of glare.*

In order to avoid excessive glare we have decided not to adopt distributions of light providing maxima of candlepower too close to the horizontal; we do not exceed 78 deg. or even 75 deg., and we obtain satisfactory results when the installations are well carried out.

(iii) *Importance of the aesthetic point of view.*

It is well known that in France, and particularly in Paris, in order to preserve the beauty of the town, we are extremely careful not to disfigure our streets; and we thus ensure that the shape of the lamp posts is in keeping with the architectural character of each urban site. Axial suspension is practically forbidden in the smart districts. It is for similar aesthetic motives that we have not installed, either sodium vapour or mercury vapour lamps (even in mixture lanterns with filament lamps) in the centres of towns.

(iv) *Importance of resistance to wear and tear and of upkeep of installations.*

In our "Recommendations for Public Lighting"* we have considered it necessary to attach special importance to questions of strength, resistance to wear and tear, weather conditions and regular maintenance, upon all of which matters English documents do not sufficiently insist. They deal with them from a geometric and photometric point of view, omitting to inform the users of the materials, processes and the practical solutions which are afforded them. We have considered it useful to make recommendations, not only concerning the equipment itself, but also the accessories (fixings—boxes—casings—screws—bolts—type of supply and control of lights—maintenance). On the other hand, I wish to draw attention to an English method which, in my opinion, is excellent: the test of maintenance after 100 hours of lighting.

(v) *Method of appraisal of the quality of installations.*

As means of appraising installations, we have recourse to two criteria:

(a) Acceptance number, with regard to which I share the scepticism of Dr. English.

(b) Revealing power, Mr. J. Waldram's definition of which I consider to be somewhat theoretical.

You will probably say: "You criticise English methods of appraising an

* These Recommendations, published in 1949 by the Association Française des Eclairagistes, have just received the official approval of the Ministère de la Réconstruction et de l'Urbanisme.

installation, but what have you to propose in its stead?" I must admit that we have not yet found a better method, though we feel the need for one.

Until some satisfactory test be found, whenever my opinion is asked about a type of installation, I can suggest no more reliable method than to make a trial installation on a section of road having the same road surface and to judge, on the spot, the effect produced, both on foot and while driving a car, thus determining the degree of uniformity of brightness of the road and the visibility of fixed or moving obstructions.

I must not fail to mention another point for which a solution is afforded by English technique. This is the gauge devised by Mr. J. Waldram to determine the siting of lights in curved streets. The theoretical basis of this gauge is perfectly logical and I think it may prove very useful to public lighting engineers. It would be interesting to know what results are obtained when this gauge is used for roads in different states of repair, or in different conditions, e.g., in wet and dry weather. Once again we have no better solution to propose, and I recognise that I must confine myself to the easy role of a critic.

Conclusion

It will be seen that the comparison of our respective doctrines only reveals differences in detail. The Association Française des Eclairagistes will shortly send the Illuminating Engineering Society and the Association of Public Lighting Engineers the complete text of "Recommendations for Public Lighting," published in 1949. We shall be very grateful to our English colleagues for any suggestions and criticisms that this document may call forth. Thus, the collaboration between our two countries will be more profitable for us in France.

Studies of Lighting and Vision in Schools

By R. G. HOPKINSON, B.Sc.(Eng.), Ph.D., *(Fellow)*.

Summary

An investigation into the problem of school lighting and vision has been made, in four stages:—

(a) A study was made of the distribution of visual acuity in a random sample of London school children, in relation to the influence of illumination level and chalkboard reflection factor. The distribution was found to agree with a distribution measured in 1928 on a similar sample. Increased illumination was found to provide the greatest benefit to those children with indifferent visual acuity.

(b) More detailed studies of the effect of illumination and contrast on visual acuity and on ease and speed of reading, were made on a selection of adults with visual acuity varying from very good (Snellen 6/4.5) to poor (Snellen 6/60).

(c) The factors which influence glare have been investigated.

(d) An analysis of visual tasks in schools was made by the M.R.C. investigators under the direction of Mr. H. C. Weston, and this analysis (of size, contrast, etc., of lettering on chalkboards) has been drawn upon, with Mr. Weston's kind permission.

The present standard of illumination prescribed by the Ministry of Education (10-ft.c., that is, 10 lumens/sq. ft.) is found to be an adequate minimum standard provided chalkboard letters are large and children sit near the chalkboard. Improvements in ease of reading result from increased illumination levels, but these increases must be substantial. Under some average conditions the improvement in ease of reading which results from the child moving four feet nearer the chalkboard is matched only by an increase of 30 : 1 in illumination level. The results of the experiment throw into sharp relief the need for the integration of the lighting with the design of school classrooms.

The paper is a study of visual conditions associated mainly with formal teaching from fixed chalkboards. Educationists are, however, advocating the replacement of such methods, in infants' schools, by informal teaching in groups, using mobile chalkboards distributed round the room. In secondary schools the present methods will probably continue for some time. The studies reported in the paper are, of course, applicable to this new approach by educationists, but further work directly concerned with group teaching may be of value at a later stage.

Introduction

The studies reported in this paper were undertaken for the Joint Committee on Lighting and Vision of the Medical Research Council and the Building Research Board. A need arose for an investigation on the inter-relation of school lighting and vision, especially the effect of the level of illumination on the ability to read from the chalkboard or instruction chart. The necessary data fell under the following broad headings:—

(a) What level of illumination is necessary on the instruction board for children with normal vision?

(b) Has a significant proportion of children in a representative sample less than normal visual acuity?

(c) What effect will lighting, above the level recommended from (a) above, have in bringing within the normal range children with slightly sub-normal eyesight?

(d) Will the effect of lighting on visual acuity be the same as the effect on ease of reading or facility of learning?

The literature does not supply the answers to these main points, and, indeed, they can only be answered by a summing up of the various factors, so that a good compromise can be achieved.

It was decided, therefore, to initiate a series of studies under conditions which, whilst not too dissimilar from school classrooms, could be controlled to enable quantitative data of engineering value to be obtained. This paper reports the results of these studies. Studies on learning facility, which were also conducted, with Dr. R. C. Oldfield of the Joint Committee, are not, however, discussed in the report.

Part I—Experimental Studies

(1.) Visual Acuity of School Children

The first stage of the work was to obtain a distribution of visual acuity on a sample of school children. Tests made on 35 adults from the Building Research Station staff had shown that visual acuity, assessed from the standard Snellen chart at 6 metres from the observer, improved with increasing illumination level on the test chart, and that, for observers of slightly sub-normal acuity, an increase in illumination level would result in a sufficient improvement in acuity, largely to compensate for their slight disability.

In relation to school lighting design, it was considered necessary to investigate (a) whether school children would show the same improvement with increase in illumination level as had been found for adults, and (b) what increase in illumination above the values prescribed at present by the Ministry of Education would enable a significant proportion of those children with slightly sub-normal acuity (who form a small proportion of any random sample of children) to compensate for their slight disadvantage.

This problem was discussed with Professor Arnold Sorsby of the Royal College of Surgeons and as a result of this discusion, the Building Research Station was enabled, through the courtesy of Professor Sorsby, to make a survey of the visual acuity of a sample of 95 children at the White Oak Hospital of the London County Council, at Swanley Junction, Kent. These children consisted of (a) a group of 59, of ages from 6 to 14, who were in the residential school at Swanley, and these could safely be taken as a completely random sample of children of those ages, and (b) children who were patients in the Eye department of the hospital. Most of these were suffering from a temporary disease (due to malnutrition) which would not be expected to affect their visual acuity and they would therefore fall within the random distribution. The others were children with sub-normal acuity, who were being given special care for their disability. They were not, therefore, likely to be part of a random distribution.

(1.1.) Experimental Procedure

Two test charts were used, one, a standard Snellen design, with black letters (reflection factor $\rho = 3$ per cent.) on white card (reflection factor $\rho = 75$ per cent.) and the other, a card prepared photographically from another standard Snellen chart (but not the same as Chart I) to yield white ($\rho = 75$ per cent.) letters on a grey ($\rho = 13$ per cent.) background. This latter chart was designed to correspond to white chalk letters on a blackboard made grey by continued use.

A large grey ($\rho = 42$ per cent.) background (approximately 5 ft. × 8 ft.)

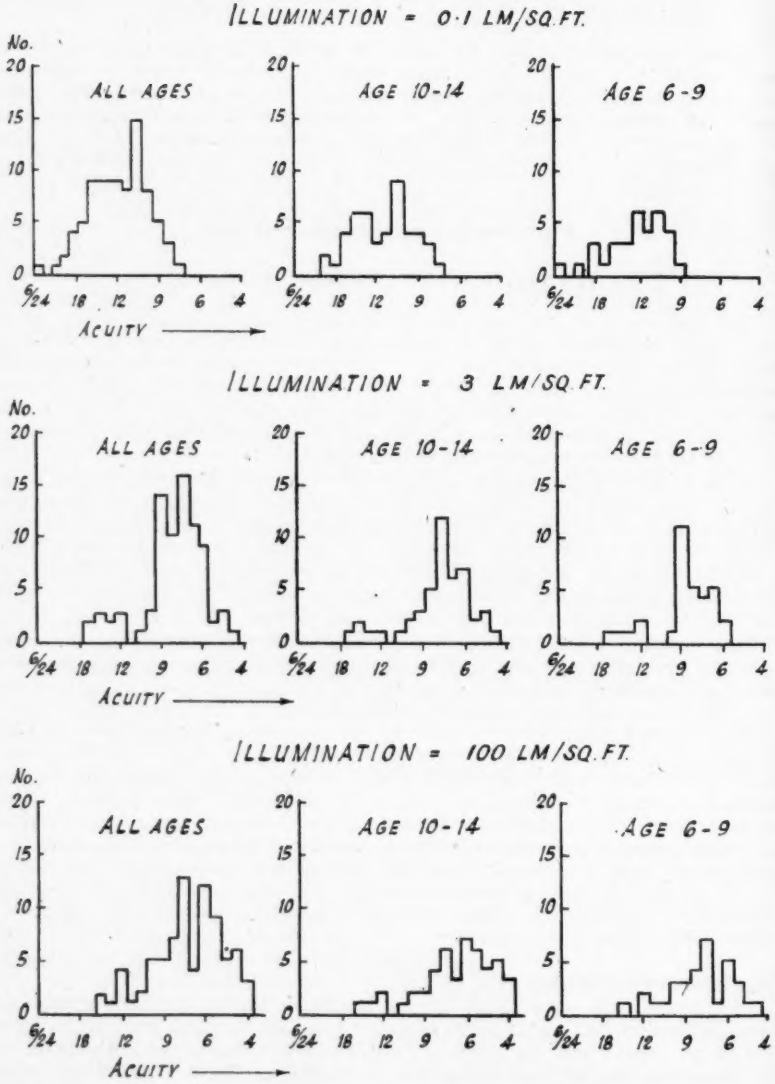

Fig. 1. Acuity distributions of normal sample of children, divided into two age groups for standard Snellen chart.

was provided as a surround to the chart. This served to avoid distraction from harsh contrasts in the immediate surround to the chart.

The brightness of the rest of the room was controlled to be of the order of, but less than, the brightness of the chart and its immediate surround. (These conditions are generally believed to be the most satisfactory for comfortable vision.)

The chart and surround were illuminated by a bank of lamps, shaded from the observer. By suitable controls in the lamp circuits, three levels of illumination on the chart and surround could be selected rapidly in turn. (These levels were approximately 0.1, 3 and 100 foot-candles, that is, lumens per square foot, i.e., ratios of approx. 1:30).

The children were selected in batches of approximately 6, and waited in a room adjacent to the test room, with the blinds partially drawn so that the average room brightness equalled that of the test room when the test chart was illuminated to the lowest level. The children were selected one by one, and on entering the test room, were asked to sit in the chair provided at a distance of 6 metres from the test chart. A few routine questions (name, age, etc.) were asked whilst the eyes completed any remaining adaptation to the general room level.

With the illumination level set at 0.1 lm/sq. ft., the acuity of the left eye, then the right eye, and finally both eyes together, was taken on the standard Snellen chart. With the younger children especially, some careful thought had to be given to the assessment obtained from the occasionally erratic reading. The same experimenter made all the assessments, and it was believed that consistency in the method of assessment was achieved throughout the whole sample.

With the illumination level remaining at the same value (0.1 lm/sq. ft.) the test chart was changed to the white letters on grey background (Chart II) and the acuity assessed again, for both eyes together. (The letters on this chart were different from those on the first chart.)

The illumination level was then slowly raised to 3 lm/sq. ft. and the acuity assessed still on Chart II. The chart was then changed, and the acuity assessed on Chart I (black letters on white background).

Finally the illumination level was raised to 100 lm/sq. ft., acuity assessed first on Chart I, and then on Chart II. After the tests the child returned direct to the classroom, without the opportunity to discuss the experiment with his friends who were awaiting their turn.

It will be realised that some care is necessary in assessing the acuity of immature readers. It was noticed that increasing the level of illumination often made little difference to the number of letters read on the final line, but a noticeable reduction in the number of mistakes made on the earlier lines. This was especially noticeable in the case of the younger children. It led to the feeling that further experiments based on a performance test, assessed in terms of the mistake rate, might yield more definite information than the simple acuity tests. It was noticed that the older children made fewer of these early mistakes, and this corresponds to experience with adults. Reading with each eye separately was much slower than with both together, but the possibility cannot be ruled out that the child had gained confidence by the third test (that with both eyes together). At the highest level of illumination, the tendency to lean forward in the chair to strain to see better was very much less marked, indicating a greater ease of seeing. This was felt to be most significant.

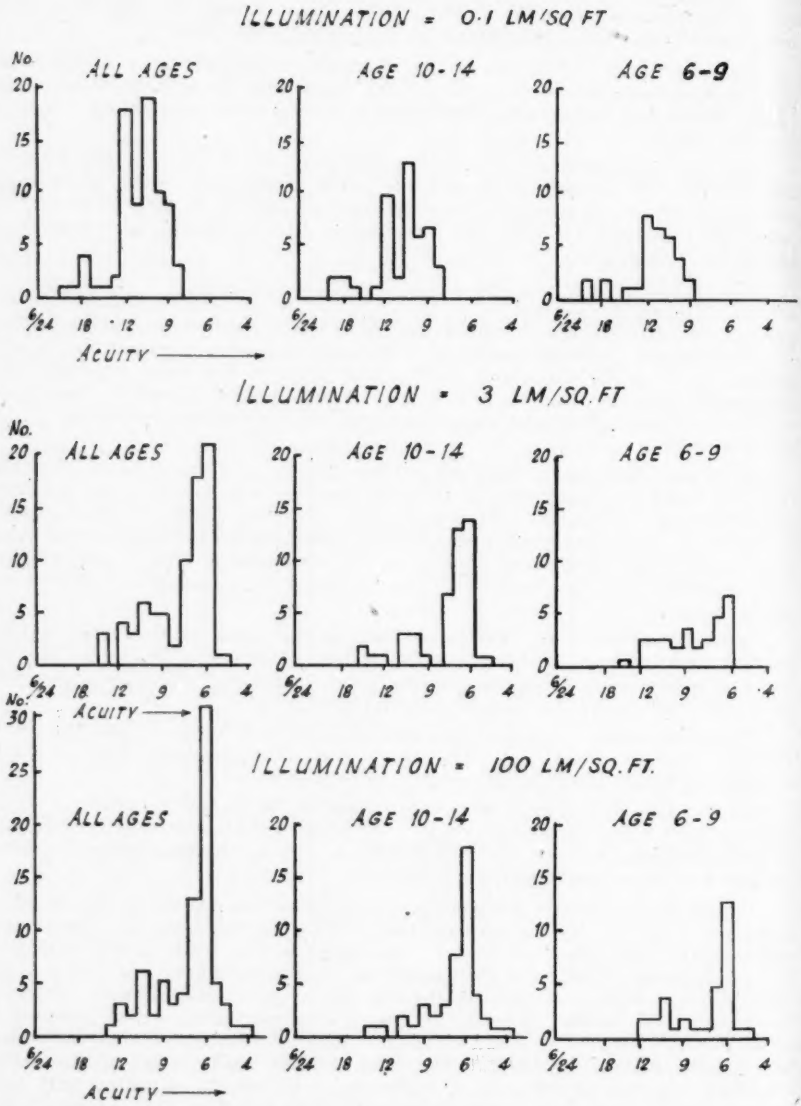

Fig. 2. Acuity distributions of a normal sample of children divided into two age groups for "blackboard" test.

1.2.) Discussion of the Results

A very brief summary of the results is given for illustration. Figs. 1 and 2 show the distribution of visual acuity for the normal sample of children (not the visual defectives) arranged in two age groups, on both the "blackboard chart" and the standard Snellen chart. Fig. 3 shows some of the relationships between mean acuity and illumination level.

(1) Considering the complete sample (Figs. 1 and 2), it is evident that the improvement effected by the increase from 3 to 100 lm/sq. ft. (although the same proportionate increase in illumination, approximately 30:1), is less marked than that between 0.1 and 3 lm/sq. ft. This also agrees with the tests made with the group of adults (see Fig. 3).

(2) The acuity measured on the standard Snellen chart is slightly poorer than that on Chart II, which corresponds to the white chalk letters on a blackboard at the lowest level of illumination. Referring to the data for the group with defective vision, it amounts to almost one whole line of the chart at the two lowest levels. (See Fig. 3.) This advantage of white letters on a dark ground at low illumination levels has previously been found by other workers.

(3) There appears to be a change in the skewness of the frequency distributions (see Fig. 1 and 2) with increase in illumination level although the change is not significant on the 95 per cent. probability basis. This skewness was more marked in the case of the blackboard chart. Its significance is that at the highest level of illumination, most children will see well with the blackboard, with little difference between individuals; a few of the normal sample will still not see as well as the majority, but they are a small proportion of the whole and could therefore, in practice, be accommodated at the front

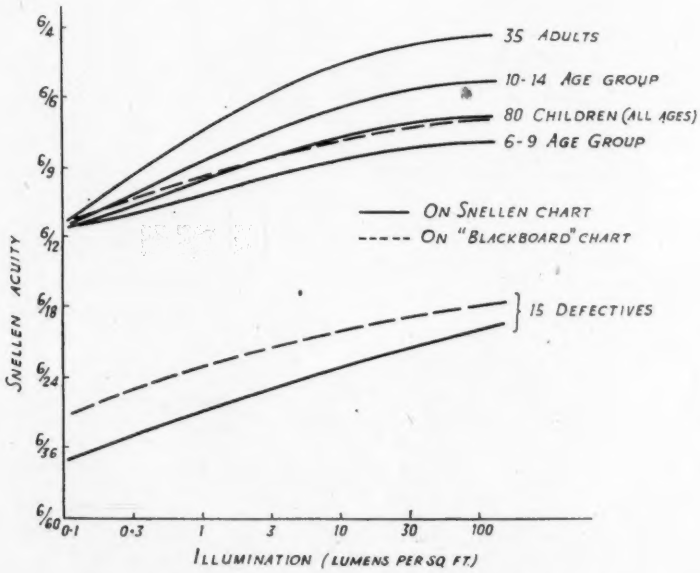

Fig. 3. Mean acuity of samples related to illumination level.

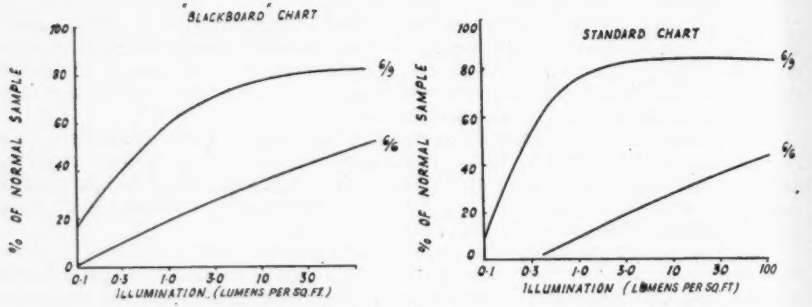

Fig. 4. Proportion of normal sample with acuity better than 6/9 or 6/6 at different illumination levels.

of the classroom. With the black-on-white chart, however, it is found that, even at the highest level of illumination, the distribution is much wider, so that some children will see quite significantly better than others.

Whilst in the case of the normal sample, the improvement resulting from the increase from 0.1 to 3 lm/sq. ft. is greater than that resulting from the increase from 3 to 100 lm/sq. ft., in the case of the 15 defectives the improvement is the same in each case. The defectives gain most by still more light (Fig. 3). It was felt that the benefit of higher illumination to the visually defective group would have been found even more marked if the assessment could be based on a test of comfort.

A first attempt has been made to interpret the data in a way which would lead to a recommendation for lighting levels in schoolrooms, based on visual acuity for reading the blackboard or other similar visual mode of instruction. Fig. 4 shows the relationship between lighting level and the percentage of children from the non-defective group whose acuity is better than 6/9 and 6/6, respectively, (a) on the Snellen chart, and (b) on the "blackboard" chart. This enables an estimate to be made of the proportion of children who can be assisted by a given increase in lighting level. The data for the "blackboard" chart (Chart II) show, for example, that at a level of 0.1 lm./sq. ft., only 15 in 100 of the children in the "normal" distribution have acuity as good as, or better than 6/9, and none have 6/6. At 3 lm./sq. ft. 73 in 100 have 6/9 or better, and 28 in 100 have 6/6 or better. Of the 27 in 100 who have worse than 6/9 at 3 lm./sq. ft., four are improved to this standard by raising the illumination to 10 lm./sq. ft., and a further three by raising the illumination level to 20 lm./sq. ft. This gives some idea of the significance of these improvements in lighting level.

If the desirable standard is taken as 6/6 (normal adult vision), 70 children in 100 have less than this standard at 3 lm./sq. ft., and each succeeding increase of 3:1 in lighting level brings in a batch of eight children above the standard. This improvement continues up to 100 lm./sq. ft. and has not reached a maximum at this level. There is thus no kind of "optimum" level of illumination; the choice of level depends on the basis of assessment. It is evident, however, that on any basis, the lower limit is in the region of 3-10 lm./sq. ft.

Finally, the normal sample was divided into two groups, one 6—9, and the other 10—14 years old. The general trend of each age group appears to be very similar. (Figs. 1 and 2.) The better acuity of the older group

is evident. This is believed to result from an acquired ability to "guess" the meaning of a letter indistinctly seen, and it probably accounts for the better average acuity of the sample of 35 adults whose results are also illustrated in Fig. 3. It is of considerable interest to note, however, that this difference between the age groups disappears at 0.1 lm./sq. ft.

(1.3.) Comparison with Previous Findings

It is of interest that the distribution of visual acuity found here agrees substantially with the only other distribution discovered in the literature. This data was taken from the L.C.C. Public Health Report of 1928 and relates to an analysis by Dr. J. H. McIlroy of a random sample of L.C.C. schoolchildren. Although the precise illumination level at which these tests were made is not given, it is reasonable to assume that it was between 10 and 100 lm./sq. ft., and the comparison has been made between Dr. McIlroy's data and the data from the present study averaged for 30 lm./sq. ft. The comparison is shown in Table I.

Table 1.

Distribution of Visual Acuity in a normal Sample of School Children, (a) by the Building Research Station (1948); and (b) by Dr. McIlroy for the 1928 Public Health Report of the L.C.C.

Sample	Visual Acuity (Snellen Chart).		
	6/9 or better	6/12	6/18 or worse
	per cent.	per cent.	per cent.
(1) CHILDREN AGES 6–9:			
(*a*) B.R.S. 1948	85	11	4
(*b*) L.C.C. 1928			
*Jewish children	74	14	12
*Others	87	9	4
(2) CHILDREN AGES 10–14			
(*a*) B.R.S. 1948	89	8	3
(*b*) L.C.C. 1928			
*Jewish children	74	11	15
*Others	86	9	8

* Dr. McIlroy's data was given in this form. The exact number of children in each category (Jewish and non-Jewish) is not known, so an average of the percentages for the two categories could not be derived. Hence both sets of figures are given here, although the division is not of significance to the present purpose. The B.R.S. sample possibly contained a few Jewish children.

(2.) Effect of Illumination and Contrast on Visual Acuity, Ease of Reading and Speed of Reading for Observers with Normal and Defective Vision

The next series of experiments were intended as a follow-up to the survey of school children's visual acuity.

It was required to study the effect of the contrast of white letters against backgrounds of different reflection factors such as might result from, for example, varying degrees of chalky dust overlying the badly cleaned board, and how the visual acuity of subjects with normal or indifferent vision would change with variation of illumination on such charts of different contrast.

It was with school conditions in mind also that if a subject could not see the chart letters at the prescribed Snellen-chart distance (6 metres) he was

allowed to move closer to the chart, just as in school a child with indifferent vision might be moved to the front row of the class in order to assist his ability to read the blackboard. Consequently, for these subjects the data are presented both in the form of "line acuity" and of "distance acuity" measurements.

The subjects were 15 adults carefully selected from the staff of the Building Research Station to cover a range of acuity from 6/4.5 (better than normal) to 6/60, and to include myopes, astigmats, and hypermetropes. For many reasons it was not possible to conduct the tests, which were somewhat fatiguing and which took some time to complete, on children. Errors in refraction were measured by Mr. J. L. H. Moss of the Medical Research Council. (A detailed summary of the visual characteristics of these observers is given in Ref. 5.)

The test charts were derived photographically from standard Snellen designs. The white letters (reflection factor approximately 78 per cent.) were seen against a grey background of reflection factors as follows:—

Chart I	63	per cent.	appearance light grey.
„ II	38.2	„ „	„ medium grey.
„ III	24.2	„ „	„ grey, medium to dark.
„ IV	13.1	„ „	„ dark grey (approx. average blackboard).
„ V	6.5	„ „	„ black (newly blackened board).

In addition, there was a standard Snellen chart (Chart VI) consisting of black letters on a white background (reflection factor 74 per cent.).

The charts were of different letters so that familiarity with one chart was of no help in interpreting another. Additional charts with the same reflection factors but giving more letters on 6/60, 6/36 and 6/24 lines were also prepared to enable low values of acuity to be assessed more accurately.

(2.1.) Experimental Procedure

The subject sat 6 metres from a near-white wall upon which each chart was displayed in turn. The whole wall as well as the chart itself was illuminated by the light sources, and the surroundings in the room (reflection factor approx. 70 per cent.) were of a brightness lower than, but of the same order as, the brightness of the wall.

After an initial period for adaptation, the subject commenced the test with an illumination of 0.1 lm./sq. ft. on the test charts. The grey charts were presented in order of increasing contrast (Chart I—V in order) with the normal Snellen chart (Chart VI) last. The subject read as far as he could on each chart. The next chart was then presented, and so on.

If the observers' acuity was so poor that nothing could be read on the chart, he was allowed to walk slowly towards it, stopping frequently, until the 6/60 line could just be read. For these observers and also for those who could see only the 6/60 or 6/36 letters, the sets of magnified charts were employed. The distance was also taken at which each of three lines of the magnified chart became readable, in order to check the relationship between "distance acuity" and "line acuity."

After the set of tests had been completed at the low level of illumination, the procedure was repeated at an illumination of 3 lm./sq. ft., and again at 100 lm./sq. ft. The same charts were used, as it was felt that familiarity with the charts would not influence the reading of the smaller letters which could be seen at the higher but not at the lower levels of illumination.

In addition to the acuity readings, subjects were invited to comment on the "readability" or the sensations of comfort or discomfort resulting from the contrasts of the various charts. These preferences were recorded. Observers were asked not to base their preferences necessarily on what they could see;

thus a chart on which little could be seen might possibly have been preferred because it was less "glaring" than a chart with better contrast. A careful note was taken of any remarks made by the observers during the course of the experiment which might help in the interpreting of the results, and also of

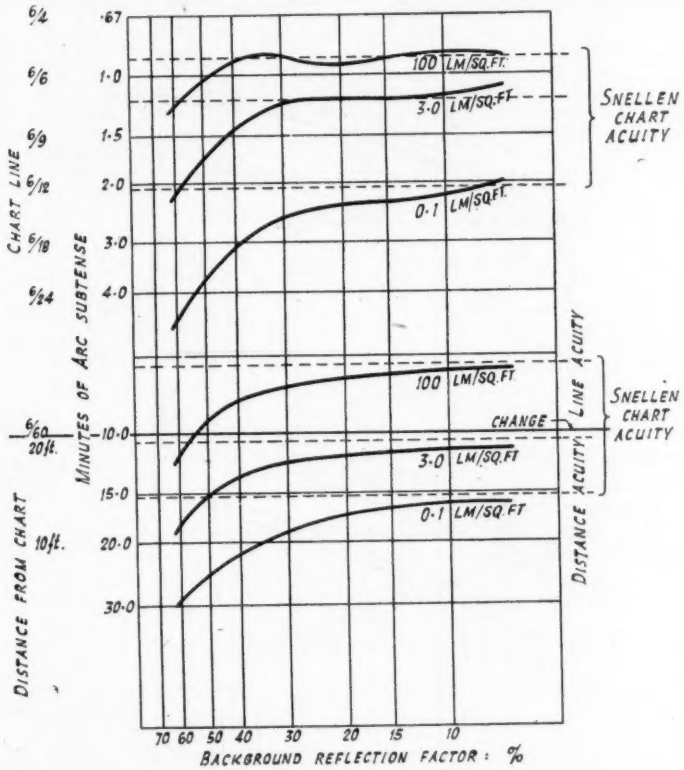

Fig. 5. Average curves showing contrast vacuity for three levels of illumination for white letters on dark background. Averaged curves for ten subjects with good visual acuity and for five subjects with poor visual acuity are shown.

their reactions to the visual tasks such as any signs of obvious strain or of relaxation.

(2.1.1.) *Results*

The effect on acuity of the degree of contrast between white letters and the blackboard is shown in Fig. 5, for the group of observers with normal acuity, and for the group with poorer acuity. The data suggested that, at any given illumination level, little improvement in acuity (as assessed by this type of chart) results from increasing the contrast between the letters and their background beyond a certain critical value. If the contrast is reduced below this value, the acuity will fall off rapidly. These critical reflection factors for black-

boards with white chalk letters appear to be about 40 per cent. at 100 lm./sq. ft., 25 per cent. at 3 lm./sq. ft. and 6 per cent. at 0·1 lm./sq. ft. The acuity achieved with these contrasts is of the same order as that achieved on the standard black-on-white Snellen chart.

The data have been plotted with a reflection factor scale for abscissae, applying to the actual charts used. The reflection factor of blackboard to give

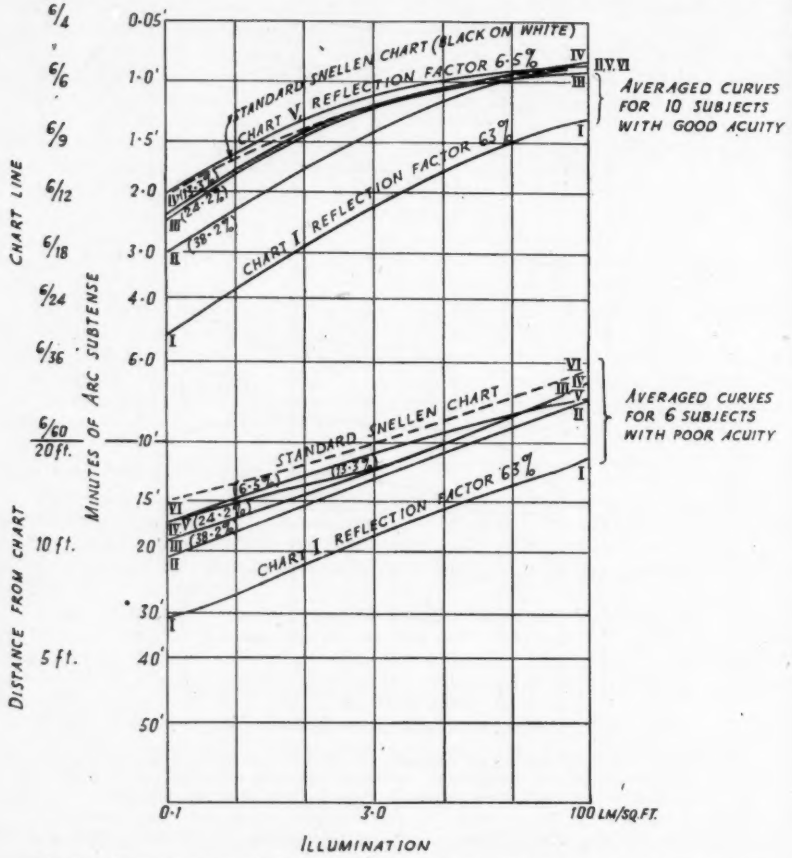

Fig. 6. Average curves showing relationship between illumination and visual acuity assessed on charts with different reflection factors.

the same contrast against white letters of lower or higher reflection factor than the letters on the test charts, which were approximately 78 per cent. reflection factor, can, of course, be calculated.

Fig. 6 gives the same measurements as those of Fig. 5, but on an illumination/acuity basis. Fig. 6 shows that for all the charts with adequate contrast, a greater improvement in acuity results from a change from 0.1 to 3 lm./sq. ft. than from a change from 3 to 100 lm./sq. ft. On the other hand, with the charts

of the lowest contrast, the improvement in acuity is the same for each equal change in illumination. This applies to the observers with good acuity. For the observers with poor acuity, the improvement in acuity resulting from the 30:1 change from 3 to 100 lm./sq. ft. is the same as that from 0.1 to 3 lm./sq. ft. on all the charts. The rate of improvement is maintained up to 100 lm./sq. ft. for observers with poor acuity.

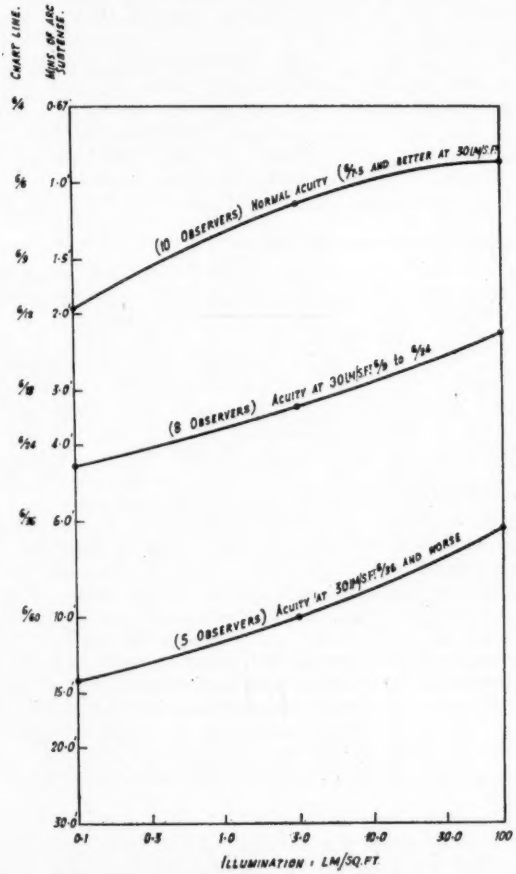

Fig. 7. Illumination plotted against acuity for standard Snellen Chart. (Averages for observers with similar acuities.)

Averaged data for the Snellen chart (Chart VI) for 10 observers with good vision (6/7.5 or better), eight observers with indifferent vision (6/9 to 6/24), and for five observers with poor vision (6/36 and worse) are given in Fig. 7.

These results confirm the evidence on the L.C.C. children of the Swanley experiment (Sec. 1), that those with poorer acuity obtained continued benefit from increases in illumination above the level at which those with good acuity derived little useful benefit.

(2.1.2.) *Comments and Preferences of Observers.*

The comments made by observers, and their preferences, were of some interest. At low levels of illumination observers clearly preferred the charts with white letters on the dark grey or black backgrounds from the point of view of comfort, even though in some cases they could not see as well as with the standard Snellen chart.

This also applied to the higher levels of illumination, except that white on grey was sometimes preferred to white on black, some observers remarking that the latter was "glaring."

It was found that, as at Swanley, even where no improvement in measurable acuity resulted from a change from 3 to 100 lm./sq. ft., many subjects read their letters more readily and quickly without straining to see them or attempting to lean forward, even at the line where no more letters could be resolved. Again there seems to be another factor, of comfort of reading which is additional to measurable acuity, and which the present series of measurements do not show. For this reason studies were next made with a reading test.

(2.2.) Ease and Speed of Reading—Experimental Procedure

The reading task consisted of a paragraph of about 16 lines, 150 words, in Times Roman fount. Nine such paragraphs in all were photographed on separate charts, and enlarged to such a size that the height of the letters corresponded approximately to that of the 6/5 line on the standard Snellen chart. Three of the charts, which were 18 in. long and 12 in. high, consisted of black letters (reflection factor about 5 per cent.) on a white background (reflection factor about 75 per cent.), three of white letters (reflection factor about 75 per cent.) on a grey background (reflection factor about 15.5 per cent., corresponding to an average blackboard), and three of white letters on a black background (reflection factor about 7.5 per cent.). One of each type of chart (black on white, white on grey, and white on black) were used at each of three levels of illumination, 0.1, 3, and 100 lm./sq. ft., and the set used first at 0.1 lm./sq. ft. was again used at 3,000 lm./sq. ft.

The experimental procedure was designed to eliminate the possibility of the observer learning the paragraph and hence influencing his speed of reading. The reading matter on each chart was selected to present as far as possible the same degree of difficulty as well as the same number of words.

The charts were seen against a white wall, in a room decorated with pale cream distemper. The general level of brightness in the room was of the same order as, but lower than, the brightness of the wall against which the charts were seen. The observer was given time to adapt to his surroundings in each of the tests. The tests on the 3,000 lm./sq. ft. level were made out of doors, the immediate surround being a plaster wall of approximately 20 per cent. reflection factor.

The test procedure was as follows:—

The observer saw the chart from the far end of the room and was told to advance toward the chart until he could just see the first few words of the chart, which were told to him just previously. At this distance, he could recognise these first words because he knew what they were, and perhaps also some of the shorter easier words in the rest of the text which he did not know, but he could not attempt to read the whole paragraph. This distance was described as the "Just Seen" distance. The observer then approached the chart until he could just read through it. It was as much as he could do to read the chart, and mistakes would be made on the more difficult words, but he could finish the chart before he became too fatigued to

read at all. This was called the "Barely Readable Distance." The time of reading was noted at this distance.

For the third criterion the observer advanced again until the chart was "Reasonably Readable." Although it was a strain to read it, the words could be seen fairly well. The time of reading was again noted. For the last criterion the observer walked forward until the chart was easy to see, no strain was involved and any further advance would not, in his opinion, improve the ease of reading. This distance was recorded as the "Easily Readable" distance.

Individual characteristics gave rise to a wide spread in the observations. Observers who had good visual acuity as given by the Snellen test sometimes took a long time over the reading test, and vice versa. These individual characteristics have not all been followed up at this stage, but may possibly be of interest when examined in detail.

Any uncertainty which observers may have had in deciding where they should stand for a given criterion of ease of reading would not, of course, influence the usefulness of the time/distance co-ordinates for the point at which they chose to stand. Observers uncertain of their criteria could still give a consistent plot between distance from the chart and reading time.

(2.2.1.) *Results.*

The procedure adopted allowed observers to choose the distances at which they wished to stand to correspond to the four criteria of ease of reading, and the time taken to read the paragraph on the test chart was noted in each case. This enabled a graph to be plotted for each observer, at each level of illumination, and for each chart, giving the relationship between distance from the chart, and time taken to read the paragraph. Each point on the graph also corresponded to a definite mental assessment of the difficulty of reading. If the "criterion" technique had not been used, the distance/time graphs could still have been obtained, but less information about the meaning of such graphs in terms of subjective impression would have resulted.

During the course of the investigation, with 20 observers, four levels of illumination, and nine reading charts, a large number of observations were obtained. For the purpose of this summary, these observations have been averaged, and only general trends are reported.

(a) *Variability of Readings.*

Individual results varied very considerably, and a study of them would probably be profitable, but has not yet been undertaken.

An indication of the spread of the observations is given in Table II, which

Table II.

Variability of Observers on Reading Test.

	Average	Range	Standard Deviation	Coefficient of Variation
Time to read at "barely readable" level (secs.)	138 secs.	88/236 secs.	41 secs.	30 per cent.
As above, expressed in terms of performance. (Ratio of time taken at "easily readable" level to time taken at "barely readable" level.)	43 per cent.	28–62 per cent.	10 per cent.	23 per cent.

applies to the black-on-white chart at the 3 lm./sq.ft. level. The figures for other conditions are similar.

The variability of the "performance" figures, in which the speed of reading at one criterion is referred to the speed at the "easily readable" level, is only slightly less than the variability of the actual times taken. It was thought that, whilst the actual times would be influenced by non-visual factors, such as ease of speech, the performance figures would cancel out these factors. This does not, however, appear to be the case.

There is, however, less variability in the average performance figures for each criterion of ease of reading. This is shown in Table III.

The coefficient of variability of the mean performance percentages shown

Table III.

Variability of Performance Values referred to Easily Readable as 100 per cent.

Criterion	Mean Performance Percentages* for 20 Observers referred to "Easily Readable" as 100 per cent.												Mean	Variability
	0.1 lm/sq. ft.			3 lm/sq. ft.			100 lm/sq. ft.			3000 lm/sq. ft.				
	W/G	W/B	B/W	W/G	W/B	B/W	W/G	W/B	B/W	W/G	W/B	B/W		
Barely Readable	35	36	34	31	40	43	41	40	43	39	41	41	39	10 per cent.
Reasonably Readable	69	67	71	62	73	76	67	70	75	68	71	77	70	6.8 per cent.
Easily Readable = 100 per cent.	——— 100 ———												100	—

*Performance Percentage = $\frac{\text{Time taken at "easily readable"}}{\text{Time taken at other criterion}}$ per cent.

W/G = white letters on grey background
W/B = white letters on black background
B/W = black letters on white background

in Table III about their mean is thus of the order of 8 per cent., compared with 23 per cent. (Table II.)

It is of interest that each criterion of ease of reading corresponds so closely to a given average performance figure. This suggests that the performance figures are a reliable guide to the degree of ease or difficulty experienced by the observer in such tests as these.

(b) *Effect of Illumination Level.*

Fig. 8 shows the influence of illumination level on the observations. As the illumination level was increased, an observer would be able to read a given type of chart (e.g., the white on black chart) at a greater distance, for the same criterion of ease of reading. The angular subtense of the letters of the chart would be less at the greater distance. Fig. 8 shows average data for some of the observations, in the form of a relationship between the illumination on the chart and the angular subtense of the critical detail of the lettering, for a constant criterion of ease of reading. (The critical detail on "The Times" Roman type was based on a measurement of spacing between the gaps in the

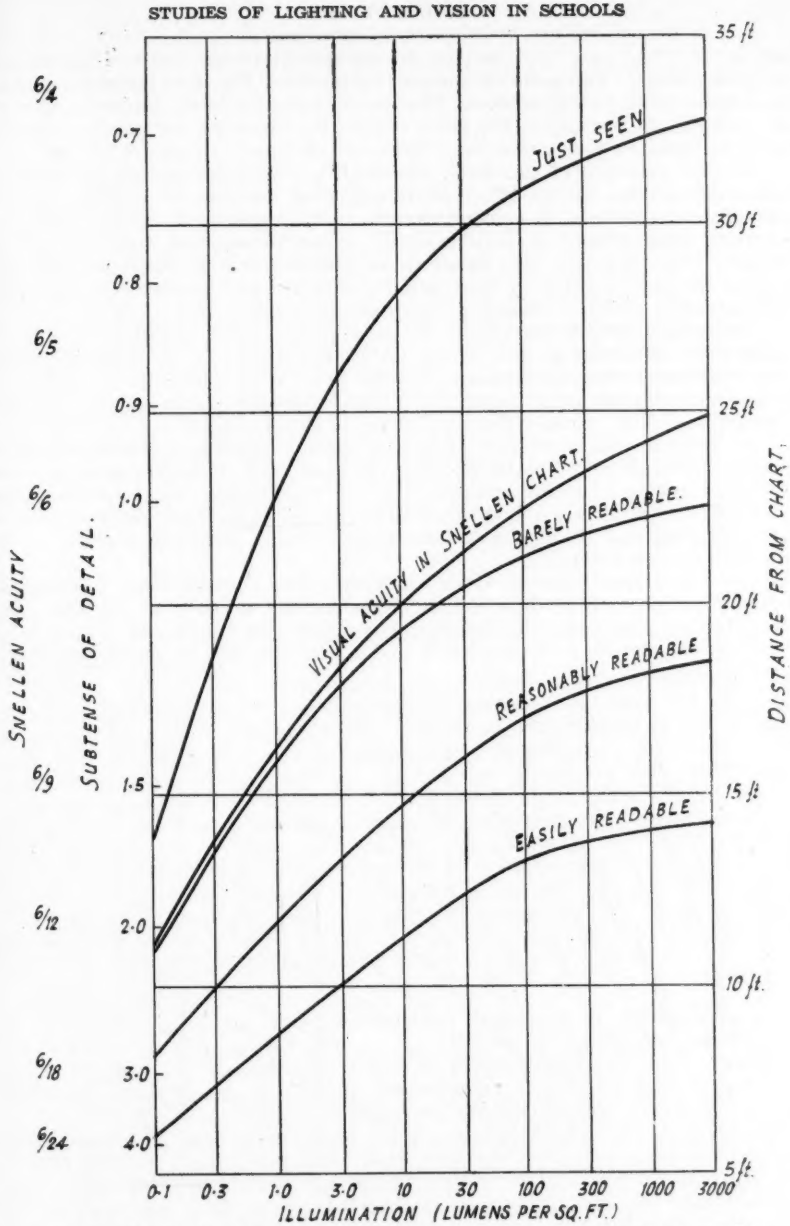

Fig. 8. Relationship between illumination level and acuity in terms of angular subtense of fine detail (average) and also distance from chart for four criteria.

letters "c," "e," and "n," and on an assessment of the relative significance of other letters. The scale of angular subtense on Fig. 8 is based on calculations from these measurements. The average size of detail happened to work out as equal to the gap in the letter "c.") It is seen by comparison with the curve for Snellen acuity that the "constant criterion" curves are similar.

On the evidence of this data, the Snellen acuity curves can be taken as reasonable guides to the effect of illumination on ease of reading, only if correctly interpreted. If a given increase in illumination is shown to produce a certain improvement in Snellen acuity, it can be assumed, from the present evidence, that this will also result in an improvement in reading conditions, in that the same degree of ease will be obtained if the observer moves the corresponding distance farther away from the reading test.

The improvement can, however, only be expressed in terms of ease of reading by reference to the "equal criterion" curves, or (since there is the close correlation with performance figures, as shown in Table III) by reference to the performance percentages. The Snellen acuity curves do not give this information. The "equal criterion" curves of Fig. 8 suggest that:—

(i) For a constant criterion of ease of reading, equal proportional increases in illumination from 0.1 to 10 lm./sq. ft. produce equal improvements in visual acuity as assessed by the critical detail of the reading test. Above about 10 lm./sq. ft., rather more than proportional increases in illumination are necessary. This agrees with all that is known about the relationship of visual acuity and illumination level.

(ii) For constant size of detail, however, equal proportional increases in illumination do not produce equal improvements in ease of reading. The more difficult the task (the smaller the detail) the bigger the increases in illumination necessary to produce a given improvement in performance: the

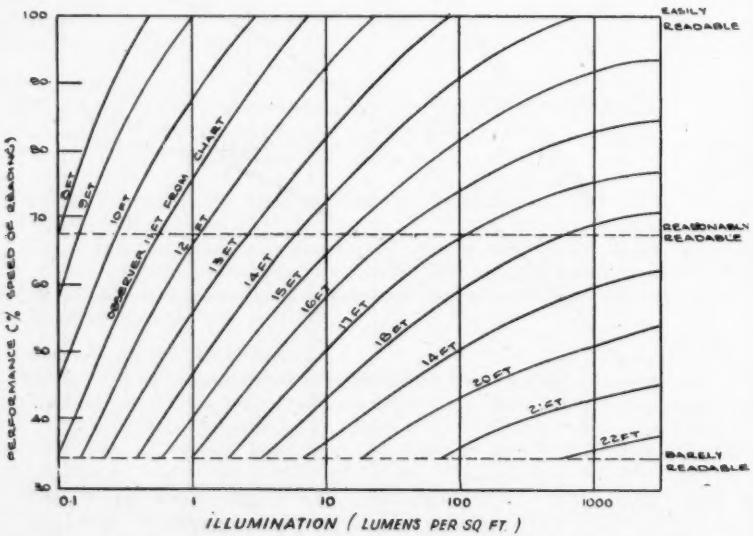

Fig. 9. Effect of illumination on performance. Average speed of reading referred to "Easily Readable" (100%).

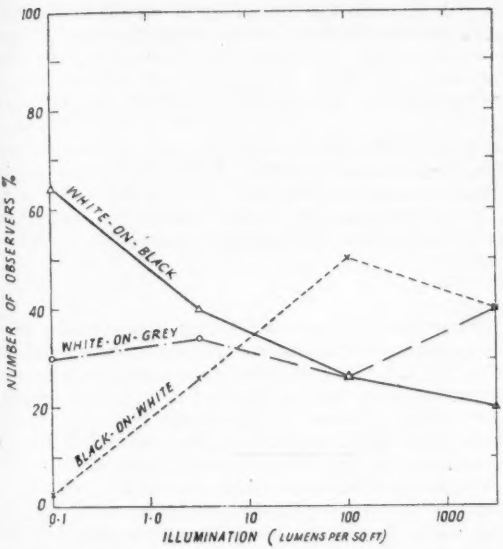

Fig. 10. Effect of illumination on percentage of first preferences for white-on-black, white-on-grey on black-on-white.

greater the desired ease of reading, the greater the illumination increase required to achieve it.

Fig. 9 shows the data plotted to include the performance percentage. This shows, in addition to the above two conclusions that:—

(iii) If the observer is sufficiently near the reading task to be able to make an attempt at reading it at low illuminations, progressive equal proportional increases in illumination produce equal improvements in his performance, expressed as a percentage of his reading speed under ideal conditions, and therefore of his ease of reading. If, however, he cannot see the task at low levels of illumination, this proportionality no longer applies, and very high illuminations indeed may not enable him to achieve maximum performance Another interpretation is: if the illumination is low, increase it; if the illumination is high, and the task is still not easy, move nearer to the task. It will be recalled that Lythgoe found that the eye is more responsive to changes in the size of the task at high levels of illlumination than at low levels.

(c) *Effect of Contrast.*

The performance of observers reading from each of the three types of chart, white on grey, white on black, and black on white, showed few consistent differences between the three types of chart, certainly nothing of sufficient significance to justify recommendations on these differences alone.

Fig. 10 is an attempt to interpret the preferences expressed by the observers, when they were asked for their comments. The relationship is shown between illumination level, and the observers' "first preference" from each of the three charts. At 0.1 lm./sq. ft., the white on black chart was preferred by 65 per cent. of the observers (13 out of 20), and the white on grey chart by 30 per cent. Only one observer preferred the black on white chart at this level. Most people firmly objected to the black on white chart. At 3 lm./sq. ft., the same order of preferences was found, but with much less

marked emphasis, and with less difference in the proportions. At 100 lm./sq. ft., 50 per cent of the observers preferred the black on white chart, the other 50 per cent. being equally divided between white on black and white on grey. At 3,000 lm/sq. ft. white on black was definitely not preferred. There were equal preferences for the other two charts, amongst the observers available at this level.

It was also of interest that most of the preferences for the white on black chart came from those observers who needed to approach closest to the charts for a given performance. (These observers did not necessarily have poor Snellen acuity.) Observers who managed at greater distances tended to prefer the white on grey chart at low levels of illumination and the black on white chart at high levels.

(d) *Acuity and Performance.*

Although the interesting differences between individual observers cannot all be discussed here, one check experiment may be mentioned. Some surprise was caused by the considerable spread between the distances for a given criterion chosen by different observers with normal Snellen acuity, and accordingly three observers, one from each extreme of the range and one about average, were asked to participate in a check. All three observers (H. H., fully corrected myope, A. B., emmetrope, and M. L., fully corrected myope) had 6/6 vision on the Snellen chart. The three observers stood in a row 18 ft. from one of the charts (white on black) with 3 lm./sq. ft. illumination.

They were then asked how they considered the ease of reading of the chart compared with the four criteria, with which they were familiar from the previous experiment. M. L. considered it to be "Just Seen," A. B. "Barely Readable," and H. H. "Reasonably Readable." Differences of the same order were noted at other distances from the chart. These differences, and the distances chosen in this case, agreed closely with the original experiment, and with the performance time ratios.

It is evident, therefore, that within the range of observers with "normal" acuity, there is a very wide spread in the distances at which various degrees of ease of reading result. This fact is of the utmost significance in relating the Snellen acuity of a child to his reading performance in class. The Snellen test must not be taken as a measure of his ability to read intelligible matter.

(3) Analysis of Visual Tasks in Schools

The analysis of visual tasks in schools made by the Medical Research Council investigators under the direction of Mr. H. C. Weston covered the whole range of visual tasks. For the purpose of the present study the data in Table IV, relating to chalkboard and similar modes of instruction, have been taken from the complete survey.

These figures were measured at a school which before the war had been a general elementary school.

(4) The Problem of Glare

Glare phenomena can be sorted into at least two distinct manifestations: discomfort glare, and disability glare. These may well be due to different physiological mechanisms.

Disability glare, i.e., the glare effect which reduces the ability to see, has been extensively studied. All the investigations have agreed, in that they show that the disabling effect of a glare source is dependent upon its intensity and not upon its brightness. Thus a small, very bright source, such as an unshaded

Table IV.

Some Measurements of Factors governing Visual Tasks in Schools.

	Range	Average
Reflection factor of chalkboard	7–33 per cent.	16 per cent.
Reflection factor of white chalk letters ...	42–60 per cent.	57 per cent.
Size of letters on blackboard—		
Printed capitals	5–9 cms.	7 cms.
,, small	2.2–3.5 ,,	2.9 ,,
Script capitals	2.5–2.8 ,,	2.6 ,,
,, small	1.7–2.3 ,,	2.1 ,,
Numbers	1.3–3.0 ,,	2.1 ,,
Size of letters on wall-charts (small)	—	4.3 ,, 2.2 ,,

lamp, will cause the same degree of disability at a given point as a window of low brightness but the same total intensity as the lamp.

Discomfort glare, on the other hand, is dependent not only on the intensity but also on the brightness of the glare source. Two sources of the same intensity but of different brightness will thus cause the same degree of disability (e.g. reduction in ease of reading, increase in minimum size of just legible letters), but the brighter will cause greater discomfort.

Discomfort glare has not been studied to the same extent as disability glare, so an investigation was undertaken. Whilst this study was not limited to the school lighting problem, some of the conclusions from the study are relevant:—

(1) An increase in source intensity (either as a result of an increase in the area of a source of constant brightness, or as a result of an increase in the brightness of a source of constant area) results in an increase in the discomfort glare, if it is not balanced by an increase in the brightness of the surroundings. The value of the surround brightness which is chosen to " balance " the source brightness to yield a given criterion of discomfort serves as an estimate of the significance of a given glare condition. A change in surround brightness of about four times is necessary to cause a change from one to the next of a series of criteria of discomfort, e.g. from " just intolerable " to " just uncomfortable."

(2) If the intensity of a glare source is increased, the surround brightness which balances the effect of the glare source must also increase. The slope of the curves relating surround brightness to source intensity for a given degree of glare will depend on the way in which the source intensity is increased. If the source intensity is increased by raising the source brightness the slope will be greater than if it is increased by increasing the source area. In other words, source brightness, in addition to source intensity, influences the discomfort effect.

(3) An increase in area of a source of low brightness is less significant in increasing discomfort than an increase in area of a source of high brightness.

(4) An increase in brightness of a source of large area is much more significant in increasing discomfort than an increase in brightness of a source of small area.

In terms of class rooms, conclusion (3) indicates that, with low brightness skies, large windows will cause little more discomfort glare than small windows,

hence the new school classrooms with their large areas of window will go far towards giving adequate glare-free illumination in dull weather.

Conclusion (4), however, indicates that, with large windows, high brightness skies (white clouds in sunshine, for example) will tend towards glaring conditions unless precautions (e.g. Venetian blinds, louvres, etc.) are taken to limit the view of the bright sky. (These precautions are also vital to reduce direct disability glare as well as the discomfort effect.)

The above conclusions will, when the studies are complete, have to be supplemented by other considerations. For example, studies are being made at the moment of the effect on discomfort glare of reducing the sharpness of the contrast between the window brightness and the general surroundings in the room, and the results may prove of interest in determining optimum window sizes.

In terms of artificial lighting fittings, the results show that definite discomfort results from the direct view of bare fluorescent lights. The intrinsic brightness of modern high efficiency fluorescent lamps is too high for them to be used without some considerable reduction in their surface brightness as seen by the observer.

Totally enclosed diffusing types of fitting should not have a brightness in excess of 1 candle/sq. in., otherwise some discomfort will result. This value is lower than the value (2.5 candles/sq. in.) given in the I.E.S. code, but this latter value was recognised, when it was published, as a definite maximum value.

There is evidence that a graduated change in surface brightness of the source, so that no harsh contrasts with its surroundings result, is beneficial.

The detailed results are the subject of a separate paper.* An interim report on the work was read in title to the 1948 conference of the International Commission on Illumination.

Part II—General Discussion

The experimental work has resulted in a considerable body of data on visual tasks and visual performance under school conditions. The applications of this data to the general problem of school lighting awaits further study by the Joint Committee for Lighting and Vision of the Medical Research Council and the Building Research Board. The following discussion is, therefore, an interim summing up of the present position arising only out of this series of experimental studies and is given solely as a guide to the experimental data reported in Part I of the paper.

The present minimum level of illumination in school classrooms prescribed by Statutory Order of the Ministry of Education is 10 lm./sq. ft. It is therefore of value to study the significance of this illumination level in relation to the experimental work.

Whilst it is clear from all the data that normal sighted subjects benefit from increases in illumination up to at least 200 lm./sq. ft. it is also clear that these benefits become progressively less marked when the illumination is increased above about 10 lm./sq. ft. The most noteworthy effect of illumination on visual acuity is that subjects with acuity poorer than normal benefit most from increases in illumination. Since some children have a poorer acuity than the normal adult standard (partly due, no doubt, to their not having yet acquired the ability to guess the identity of indistinct letters), arguments for increasing the illumination level in ordinary classrooms in order to improve visual acuity

*To be published in the Transactions in due course.

are on firm ground. Defective or partially-sighted children are, of course, a special problem not dealt with in this report.

Referring to Fig. 4 it is seen that increases in illumination above about 10 lm./sq. ft. make little or no difference to the number of children who have 6/9 vision (fairly "normal" for a child, but 6/6 is considered as "normal" for adults). At this level of illumination about 80 per cent. achieve 6/9 acuity, and further increases in illumination do not add to this proportion. At this level about 30—35 per cent. of children have vision as good as 6/6, at 30 lm./ sq. ft. about 40 per cent. have 6/6, at 100 lm./sq. ft. 50 per cent. have 6/6, and the proportion appears still to be increased with further increases in illumination. Thus, at the level of illumination (10 lm./sq. ft.) at present prescribed by the Ministry of Education, 80 per cent. of children have an acuity of 6/9 and 30—35 per cent. have 6/6.

As these assessments of visual acuity were made on a "blackboard" chart as well as upon the standard Snellen chart, it is possible to assess the significance of the data directly in terms of letters on a blackboard. A subject with 6/9 vision can read a letter $\frac{1}{4}$ in. high at 10 ft., and a letter $\frac{3}{4}$ in. high at 30 ft. These values are probably representative of the distances from the blackboard to the front and the back rows of a class respectively. (The effect of the irregularity of long-hand lettering on the blackboard on its visibility is probably balanced out by the familiarity of such characters as compared with the unfamiliar and deliberately ambiguous shapes of some of the Snellen letters. Hence direct deductions have been made from the Snellen chart data.)

The overall height of letters and numbers assessed by the M.R.C. investigators (Section 4) is equal to or greater than $\frac{3}{4}$ in., so that the standard of acuity achieved by 80 per cent. of children at the 10 lm./sq. ft. level appears adequate to enable normal-sized chalkboard letters to be recognised. Some letters and figures, such as the indices in algebraic equations, are, however, rather smaller than $\frac{3}{4}$ in. (some as small as $\frac{3}{8}$ in. have been observed in some measurements made by Building Research Station) so that the 6/9 level of acuity is not really adequate for children who are doing more advanced studies in secondary schools.

On this simplified basis of assessment it seems that the present recommended level of 10 lm./sq. ft. is not over-generous to the more advanced student (e.g. in

Table V.

Reading Difficulty and Reading Distance for Average Observer with 6/6 Vision.

Size of White "Times Roman" Script Letters on Dark Grey Background	Distance of Average Subject from Letters, Illuminated to 10 lm/sq. ft., to make the Reading Difficulty Correspond to:		
	Easily Readable (100 per cent. Speed)	Reasonably Readable (68 per cent. Speed)	Barely Readable (35 per cent. Speed)
	feet	feet	feet
$\frac{3}{4}$-in. (small algebraic indices)	16	21	25
Numbers, smallest (1.3 cms.)	21	28	33
average (2.1 cms.)	34	47	55
Script, smallest (1.7 cms.)	28	38	45
average (2.1 cms.)	34	47	55
Printed script, smallest (2.2 cms.)	35	48	56
average (2.9 cms.)	46	62	73

the 13—16 and 16—18-year-old groups) who has to deal with more hurried, smaller and less legible script.

From the data on the speed of reading tests on 20 adult observers with normal 6/6 vision, on Times Roman script (which is at least as legible as school blackboard writing), the following table has been derived:—

Most normal blackboard matter with 10 lm./sq. ft. illumination will thus be easily readable even at the back of the class, but small script and small numbers will be on the borderline. The smallest numbers measured and reported by M.R.C., and the smaller algebraic index figures which Building Research Station have noted, will be barely readable at the back of the class, although they will be easily readable towards the front. Small changes in distance from the board, make very definite changes in the speed of reading and the ease of reading.

The effect of illumination level and of distance of the subject from the blackboard in terms of the speed of reading performance is illustrated most clearly in Fig. 9.

It is evident from Fig. 9 that very large increases in illumination are necessary to improve ease of reading by useful amounts. The law of diminishing returns operates—the higher the illumination, the greater the proportional increase necessary for a significant improvement.

On the other hand, it is clear that an increase in the apparent size of the visual tasks makes a material improvement in ease of reading.

Conclusions

If classes can be designed to enable children to sit near to the instruction board, useful assistance to vision results. If, however, the design of the classroom and the number of children in the class precludes all the children sitting near enough to the instruction board for easy reading, improved lighting will be of value, but the increase in the illumination level may have to be very appreciable to be of real value.

If the illumination in a schoolroom falls below 10 lm./sq. ft. it can be shown that the visual tasks will become difficult for many children. 10 lm./sq. ft. appears to be a significant level below which troubles arise and should, therefore, be considered an absolute minimum standard of school lighting. It can, of course, also be justified as an absolute minimum on other considerations, such as alertness and attentiveness.

Sufficient evidence is available to show that children with indifferent vision benefit most by increases in illumination level. Where it is known that a significant proportion, say 25 per cent., of children have indifferent vision, the illumination should not be allowed to fall below 20 lm./sq. ft. The increase from 10 to 20 lm./sq. ft. produces an improvement of about 10 per cent. in performance in reading a blackboard, and it is felt that even this small improvement is worth while, in such cases.

Increasing the apparent size of a visual task effects a great improvement in the ease of seeing. Whereas an improvement from "barely readable" to "reasonably readable" may be achieved only by an increase in illumination of 3 to 100 lm./sq. ft., the same improvement can be effected by the child moving 4 ft. nearer the blackboard (18 ft. to 14 ft., see Fig. 9). Consequently in classrooms for higher studies (algebra, trigonometry, etc.) involving smaller and less careful blackboard lettering, every effort should be made, especially in the design stage of the school, to ensure that children will sit near enough to the

blackboard for 100 per cent. ease of reading. *High levels of illumination cannot repair bad design.*

If possible, children should be graded from front to back of the class according to their visual performance on a reading test, *not necessarily their Snellen chart acuity* (See Part I, Section 2(d) above).

Assuming a minimum illumination level of 10 lm./sq. ft. the following table of maximum permissible distances from the chalkboard or wall chart can be derived from the data. They should be taken as absolute maxima, for no allowance has been made for the greater ability of adults (on whom many of the experiments were made) to interpret indistinct lettering. If the experiments had all been made on children, the distances might well have been reduced. The distances are averages, and it is known that individuals with the same visual acuity differ widely (by $\pm$ 2 feet at least) in the distances they choose for adequate reading performance.

Table VI.

Suggested Maximum Distances from Desk to Chalkboard for Different Reading Tests on the Chalkboard or Wall Chart, with a Minimum level of Illumination of 10 lm./sq. ft.

Type of Test	Maximum Distance
Algebra, Trigonometry	not more than 15 feet
Tasks involving script writing*	,, ,, ,, 25 ,,
Tasks involving print*	,, ,, ,, 30 ,,

* Letters never less than 1-in. high.

No change from the standard blackboard with white chalk appears to be needed. Most subjects prefer white letters on a grey background at 10-20 lm./sq. ft. and their visual acuity does not fall off even if the reflection factor of the blackboard is as high as 25 per cent. with good white letters, or about 20 per cent. with average white letters. It is also possible to consider the use of coloured boards of reflection factors of 20 per cent. or less, used with white chalk. (Some work on coloured boards is being undertaken at the Building Research Station.) The preferred reflection factor range appears to be 8 per cent. to 15 per cent. (dark grey).

If, however, values of illumination in excess of 30 lm./sq. ft. are commonly experienced (as in some schools of modern design on bright days) the preference of some people for black letters on a white ground at very high levels of illumination must be recalled. It is doubtful, however, if a change need be considered unless the illumination is consistently 100 lm./sq. ft. or over.

The above conclusions relate to the amount of light necessary on the teaching board for adequate visual performance. These necessary levels of illumination must be provided by light sources so placed that they introduce no visual conflicts. Bright sources of light (either windows or artificial sources) placed near the instruction board form a competing focus of attention. These factors form the subject of further field studies.

The studies on glare, briefly summarised in Section 4, Part I, enable the balance between the source brightness and the surroundings to be achieved. Here again, however, there is no optimum relationship between source and surround brightness. The greater this brightness difference, the more uncomfortable will be the result. If the source is large, and its brightness is high, it may not be possible to achieve comfortable conditions however bright the sur-

roundings are made. The only remedy is to prevent light from the source reaching the eye directly, by the use of louvres or other restricting devices. Thus windows of sufficient size to permit adequate day lighting (to the Ministry of Education's requirements) should be fitted with some form of light control to reduce the sky brightness on bright days; louvres, venetian blinds, or translucent curtains may be satisfactory. In the case of artificial lighting, no lighting fitting in the field of view in a room lighted to a minimum illumination of 10 lm./sq. ft. should have a brightness greater than one candle per sq. in. This may be difficult to achieve economically at present with commercial equipment. Bare fluorescent lamps and 14 in. totally enclosed opal globes lamped with 200-watt lamps are too bright for comfort. Neither of these types of fitting is recommended, and fortunately both appear to be about to be superseded by better designed equipment.

These conclusions are not exhaustive; they arise from direct deductions from the data of the experimental work reported in this paper. Other factors may result in modifications, and it is hoped that it will soon be possible to bring together all the work which has been done on the related problems, and thence to formulate more general recommendations of wide application.

Acknowledgements

The work described in the paper is part of the research programme of the Building Research Board, and is published by permission of the Director of Building Research. It was undertaken under the aegis of the Joint Committee on Lighting and Vision of the Medical Research Council and the Building Research Board. Acknowledgments are particularly due to Mr. H. C. Weston, who advised at different stages of the work, and to his colleagues of the M.R.C., who undertook some of the experimental work incorporated in the paper. The main experimental studies were made by Dr. M. Gilbert and Mr. P. Petherbridge, of the Building Research station.

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Fellowship

The Council have accepted the following applications for Fellowship of the Society:—

H. F. Gillbe, W. F. Griffiths, J. L. H. Moss, A. H. Owen,
J. A. Prowse, D. W. Tyrrell, C. C. Veitch.

Obituary

PRESTON S. MILLAR

We deeply regret to announce the death on June 17, at the age of 69, of Mr. Preston Millar.

Preston Millar was very well known as president of The Electrical Testing Laboratories of New York City, an organisation run by a group of electric supply companies which, after many years, suddenly decided that they no longer needed to run these testing laboratories and, out of the blue, Preston Millar and his associates were told that it was intended to close the place down and they could seek for new occupations. It was obvious to Preston and his colleagues that the laboratories, as an independent organisation, had done and could do much useful work, and they promptly proceeded to collect together the means whereby they could continue to run the organisation as private enterprise, without the support of the supply companies. It was a difficult decision to take and gave them all a period of considerable anxiety, but Preston remained buoyant, and the laboratories have continued to do useful work.

Preston Millar was one of the founders of the American Illuminating Engineering Society, was its president in 1913, and was awarded its Gold Medal in 1945. In offering him the Gold Medal the Society recorded that—

> "For nearly half a century Mr. Millar has been an outstanding worker and leader in the lighting field, contributing enthusiastically his time and effort to the advancement of the science and art of illumination and to the promotion of the Illuminating Engineering Society. In that time he has made many notable contributions, technical and otherwise, in the various aspects of lighting, though most especially in the fields of light measurement and street lighting."

He was co-developer with the late Dr. C. H. Sharp, of the Sharp-Millar Photometer, which helped provide more accurate measurements of illumination and thus advanced the scientific basis of lighting practice.

Throughout the years Mr. Millar exercised a strong influence on the advances made in street lighting practice. His studies on the subject of silhouette vision, demonstrated at the Convention of the Illuminating Engineering Society in 1910, had a marked influence on the thinking of engineers and led to a better understanding of the art of street lighting. Under his guidance as chairman and member of the I.E.S. Committee on Street Lighting, street lighting practice acquired a general engineering agreement as expressed in codes of the I.E.S.

Preston Millar was in this country not so long ago, and it was typical of him that he took the opportunity of repaying in his own way the hospitality he had received on a previous visit. Those who were fairly intimate with Preston would sometimes receive from him communications containing the results of searchings of a mind which, ever restless in its search for the truth, could rest quietly on an idea which, when he had made it his own, he clothed in unusual language.

Preston Millar was well known for his work in connection with the International Commission on Illumination and he led the American delegation to the Paris Conference last year. His friends in many parts of the world will join us in offering to Mrs. Millar our sincere sympathy.

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members.

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Register of Lighting Engineers

The Council have accepted the following applications for inclusion on the Register of Lighting Engineers:—

H. Atherton, B. F. W. Besemer, G. F. A. Hart, C. J. N. Horner, F. T. Milne, W. L. Quinn, E. Smith, W. A. Smith, W. S. Veness, H. Walton.

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